S. Hrg. 99-503

GLOBAL WARMING

HEARING

BEFORE THE

SUBCOMMITTEE ON TOXIC SUBSTANCES
AND ENVIRONMENTAL OVERSIGHT

OF THE

COMMITTEE ON
ENVIRONMENT AND PUBLIC WORKS
UNITED STATES SENATE

NINETY-NINTH CONGRESS

FIRST SESSION

DECEMBER 10, 1985

Printed for the use of the Committee on
Environment and Public Works

U.S. GOVERNMENT PRINTING OFFICE
57-260 O WASHINGTON : 1986

S321-18

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GLOBAL WARMING

TUESDAY, DECEMBER 10, 1985

U. S. SENATE,
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS,
SUBCOMMITTEE ON TOXIC SUBSTANCES AND
ENVIRONMENTAL OVERSIGHT,
Washington, DC.

The subcommittee met at 10:08 a.m., in room SD-406, Dirksen Senate Office Building, Hon. Dave Durenberger (chairman of the subcommittee) presiding.

Present: Senators Durenberger, Baucus, and Burdick.

OPENING STATEMENT OF HON. DAVE DURENBERGER, U.S. SENATOR FROM THE STATE OF MINNESOTA

Senator **DURENBERGER**. Good morning, welcome to what is probably one of the more unusual Senate hearings, a difficult one to be sure, and in preparing for this morning's session, I have done a fair amount of reading, which I never felt was unusual for a Senator, and a fair amount of thinking, as well.

My conclusion is, that grappling with this problem is going to be just about as easy as nailing jello to the wall. If the scientists that we are going to hear from this morning are correct in their fears and predictions, in the next century, the American Midwest, which I represent, may look like the dust bowl of my childhood.

Indeed, things could be even worse. Because as one scientist after another has made clear, we are now conducting the ultimate environmental experiment with our atmosphere.

Depending upon whom you ask, the consequences could be a disaster of biblical proportions or just maybe nothing. Unfortunately, more and more of the bets are on biblical and fewer and fewer on nothing.

One of the frustrations of dealing with this issue is that it is virtually beyond the grasp of human imagination. Despite what the best scientific minds in the world tell us, our instinct in this case is to want to reject them out of hand. After all, commonsense tells us that Chicken Little was wrong, the sky could never fall and the ice caps could never melt, and yet it is true, the Earth was not always as we know it today.

Not only was San Francisco once beneath the sea—and this will come as a shock to the assistant majority leader of the Senate—so was Wyoming.

On a casual stroll through the oil rich plains, ancient shells can be pried from the rocks. So I think this is a difficult hearing because even though I know, intellectually, that the ice caps could melt and the coastal areas could flood and the plains in Minnesota could become parched and barren, all of my instincts are toward disbelief.

It is simply inconceivable to most of us that some of these predictions could come true. But a century ago, how much of the modern world today was conceivable? H.G. Wells novels were simply science fiction, nothing more, and today they would be considered science and not fiction.

In short, I can't help but think about Hamlet's advice to Horatio: "There are more things in heaven and earth than are dreamt of in your philosophy."

What has precipitated this hearing is a rather extraordinary statement from a group of scientists from 29 nations. They met about 2 months ago in Austria, under the auspices of the World Meteorological Organization, the United Nations Environmental Program, and the International Council of Scientific Unions.

Many of the attendees were government scientists; others were from universities and research institutions. It was, as far as I can determine, a collection of the finest scientific minds in the world on this subject. They all agreed on what they have never before been able or willing to say collectively: That we can no longer assume the temperature of the world is stable.

There have been previous Senate hearings on this subject, but the last of them was back in 1979. That was my first year in the U.S. Senate and my first year on the Governmental Affairs Committee and my first impression of the problem. Thanks to Abe Ribicoff, since then, we have learned a great deal.

As I understand it, the level of confidence and the dire predictions of the global environment is greater than ever before. Also, we have significantly increased our understanding of the possible consequences. Unfortunately, the progress in both of these areas is more likely to aggravate our fears than calm them.

But we have also learned that there are solutions other than a freeze of industrial or technological progress. In 1979, solutions were generally limited to reducing or eliminating the burning of fossil fuel.

Frankly, that was one of the burdens of the issue. It raises the specter of having to return to preindustrial times in order to implement a solution.

But that is no longer the case. We now know that progress could be made by controlling other gases; oxides and nitrogens, CFC's; methane, to name but three.

In fact, some solutions to global warming probably should be adopted on their own merits. The loss of forests in Africa is something, for example, that has caused agricultural activity to decline and environmental damage to increase. Reforestation would help those countries feed and clothe themselves as well as helping to slow the prediction of global warming.

Before I begin this hearing, I would like to make one final observation. Since its inception, this issue has been described as the greenhouse effect. That is an accurate shorthand way of describing the transparency of the atmosphere to the warming rays of the sun. But it is an entirely misleading catch phrase for the consequences of this warming.

A more accurate description would be climatic destruction. Because the conditions of temperature, of rainfall, humidity and seasonal change which today prevail could be gone, possibly forever.

I believe one witness will tell us the rolling fields of the American Midwest could be dustbowls, not breadbaskets. Coastal cities could be entirely under water because of ice melt, and perhaps none of this will happen, or perhaps it will happen if we fail to act. But we will be wise and farsighted enough to find and implement solutions.

Having already slowed progress by taking more time than I should have, perhaps we should now start this hearing so that we can address some real solutions. Before I do, let me turn to my colleague from Montana and the ranking member of our subcommittee.

OPENING STATEMENT OF HON. MAX BAUCUS, U.S. SENATOR FROM THE STATE OF MONTANA

Senator **Baucus**. I thank the chairman.

Mr. Chairman, this is obviously a very important hearing on a very important subject. There has been a lot written about the greenhouse effect; a lot of discussion about potential problems of adverse climatic conditions, if the assertion is correct. It is my hope that today will be a continuation of increasing public dialog of the potential problems of that problem.

The more that, not only members of Congress, but the public better understands what is at risk here, the more likely it is that not only this Congress, but the country will find some solutions.

I am sure that some of the problems of the effect are not well documented; they are not well understood, but enough is well documented, enough is well understood in order for us to try to take some concrete steps forward. I know, by the witnesses that we have before us today, that we will take some steps in that direction. It is the challenge before us to not stop there, but to continue moving so that we try to solve some of these problems before they get worse.

I look forward to the hearing.

Senator **Durenberger**. Max, thank you. Our colleague from North Dakota. Quentin, you have been around a little bit longer than the rest of us. Do you have some observations?

Senator **Burdick**. Yes, I would like to start with the witnesses.

Senator **Durenberger**. There is true wisdom.

Our first witness is our colleague, Senator Albert Gore from Tennessee.

Thank you very much for being here. Your full statement will be made a part of the record, as is your record of commitment to dealing with these kinds of issues.

STATEMENT OF HON. ALBERT A. GORE, JR., U.S. SENATOR FROM THE STATE OF TENNESSEE

Senator **Gore**. Well, I appreciate the kind words, Mr. Chairman, Senator Baucus, Senator Burdick. I appreciate your courtesy in allowing me to appear as a witness here this morning. I would like to congratulate this subcommittee for its leadership in calling a hearing on this important issue, which has been too often ignored by policymakers in a position to address the problem.

As has been indicated already, this is a difficult issue to approach as a policymaker. We in the House and Senate, respond to shorter-term deadlines, generally speaking, such as the next budget cycle, and an issue that forces us to look into the next century and contemplate consequences of a magnitude far beyond those we are accustomed to dealing with is very difficult to approach.

However, the fact remains that this period of history in which we are living is very different from any other in the history of mankind. Modern man has acquired the ability, through technology, to catastrophically modify the fragile atmosphere of our planet. Simply burning fossil fuels for warmth could have the insidious, long-term effect of warming the globe.

The build up of carbon dioxide, as well as other trace gases, traps radiation, causing the now well-known greenhouse effect. If today's worst scenarios become tomorrow's facts, we will then have only a few decades in which to ameliorate the impact, which could range from drought in the Midwest to floods in all coastal areas.

For those unfamiliar with the greenhouse effect, it may sound more like a plot for a bad science fiction novel than a serious environmental issue, deserving public policy review of the highest order. Given its serious and potentially drastic impacts, Federal research and study efforts must place the greatest priorities on solving the mystery surrounding the greenhouse effect. Otherwise, future generations may experience a science fiction story coming true.

My interest in the greenhouse effect goes back several years and includes three congressional hearings which I chaired in the House. During the first hearing, in 1981, a number of prominent scientists, including Roger Revelle of the University of California, testified that the greenhouse effect was no longer a theoretical entity, but a well documented scientific consensus.

I was struck, at that 1981 hearing, by the fact that there was really no longer any dispute among the scientists in the relevant fields of study that the phenomenon was real.

I believe that hearing perhaps marked one of the first times that a consensus had emerged within the scientific community. The evidence to substantiate the conclusion propounded by Professor Revelle was not long in coming. In 1982, James Hansen of NASA and George Coupa of Columbia University testified that the rise in carbon dioxide levels could be scientifically correlated very closely to the rise in the Earth's mean temperature, a shrinking of the polar ice caps and the resulting rise in the Earth's mean sea level.

At that time, the Washington Post, in an editorial, stated that the greenhouse effect was no longer just a theory for the sandals and granola crowd. It was in the mainstream of scientific thought.

The most comprehensive evaluations of the greenhouse effect were presented at the third hearing in 1984. An EPA report predicted that there would be a global temperature increase of 3.6 degrees fahrenheit by the year 2040 and a rise as much of as 9 degrees fahrenheit by the year 2100. This would result in sea level increases ranging from 4.5 to 7 feet by the end of the next century.

It is important to realize that the temperature increases would not be uniform all over the world. They would be much higher at the polls and lower near the equator.

Consequently, the effect of the melting phenomena is much greater than would be associated with an increase of only a few degrees at the poles. A few degrees worldwide translates into a much higher temperature increase at the poles.

A report from the National Academy of Sciences was more conservative in its projections. The NAS projected a 2 to 8 degree rise in fahrenheit temperature, along with what they describe as a modest 2½-foot rise in sea levels by the year 2100.

The major differences between the two studies was that EPA included an impact of greenhouse gases such as freon and methane, as well as carbon dioxide. The NAS projections, however, were based solely on increased CO_2 compilations.

Since the release of those two studies, probably the most significant event to occur has been the conference on the greenhouse effect that brought scientists from 29 countries to Villach, Austria this past October, to which you have referred, Mr. Chairman. These scientists concluded that greenhouse gases are likely to be the most important cause of climate change over the next century.

This conclusion was the basis for a recommendation that governments should take into account this assessment in their policies of social and economic development, environmental programs and control of emissions of radioactive gases.

In the past few years, the scientific community has moved from uncertainty about the greenhouse effect to specific recommendations on how to address the issue.

However, there are still disagreements as to the severity of the effect and the amount of time that we may have in order to ameliorate its impact.

In order to decrease the scientific uncertainties and to provide more information for policymakers, I am proposing legislation to expand and focus scientific efforts on the greenhouse effect and its consequences for society. The legislation would call for the establishment of an international year of scientific study of the greenhouse effect and would request that the President take steps to begin this worldwide cooperative investigation.

This would be just the beginning. Many of the studies would need to continue for years. The legislation would: one, coordinate and promote domestic and international research efforts on both the scientific and policy aspects of this problem; two, identify strategies to reduce the increase of carbon dioxide and greenhouse gases; three, study ways to minimize the impact of the greenhouse effect; and four, establish long-term research plans.

The concept of an international year of study has been used successfully in the past. In fact, ironically, the best and most complete collection of data based on atmospheric concentrations of carbon dioxide began in 1957 as a result of the International Geophysical Year.

At that time, the sampling station at Mauna Loa, Hawaii, was established, and today, statisticians are still collecting some of the most important data from that station. Now, more than ever, we stand at the door of opportunity, wondering whether the door will close before we act to control the greenhouse effect or whether that door will remain open long enough for us to establish a workable corrective policy.

Again, Mr. Chairman, I would like to thank you for your courtesy in allowing me to testify here and for your leadership in addressing this issue on behalf of all of us.

Senator **Durenberger**. Thank you very much for your thoughtful statement and for reminding us about passing on the problems of today to the people of tomorrow and of satisfying today's special interests without any consideration for the consequence to the generation following.

Quentin, do you have questions you would like to ask our colleague?

Senator **Burdick**. I have some questions, how long have we got?

Senator **Gore**. Well, the scientists who will testify later can provide better speculation on that than I can. However, let me summarize for you briefly what they have said during the hearings that I had on this subject. There is probably more dispute about the timeframes involved than about any other aspect of this.

There is one thing on which virtually all scientists agree: the effect is real. We can't wish it away. We can't pretend that it doesn't exist. It is real. It can be proven scientifically.

The magnitude of its impact and the timeframe during which the impact will be felt are cloaked in uncertainty, partly because of a lack of scientific knowledge. This is due to the fact that we haven't concentrated a research effort in these areas.

Specifically, we don't know what reactions might take place in the cloud system, just to take one example, and how that would interact with the forces producing this phenomenon. Such interactions should be the object of intensive research.

To specifically answer your question, the earliest estimates indicate that the effects could begin to be felt early in the next century.

Senator **Burdick**. All right.

Senator **Durenberger**. Al, would you like to join us? I know you probably have other commitments this morning.

Senator **Gore**. I appreciate the offer. For such time as I can, I would like to very much. Thank you.

Senator **Durenberger**. Our next witness is Dr. Carl Sagan, Cornell University. He needs no introduction. He comes to us today from the Center for Radio Physics and Space Sciences.

We welcome you and are very pleased that you would take the time out of your schedule to come to Washington—where everything seems to be living in today and not in tomorrow—to share with us your particular view of how our past and our present may well effect our future.

Carl, thank you very much.

STATEMENT OF DR. CARL SAGAN, CORNELL UNIVERSITY CENTER FOR RADIO PHYSICS AND SPACE SCIENCES

Dr. **Sagan**. Thanks very much, Senator Durenberger, Senator Gore, Senator Burdick. I am glad to be here. As I understand, my function is to give some sense of what the greenhouse effect is; to try to say something about the greenhouse effect on other planets; to, again, underscore that this is a real phenomenon; and then perhaps I can take the liberty to say a few remarks about what to do about it.

The power of human beings to effect and control and change the environment is growing as our technology grows, and at the present time, we clearly have reached the stage where we are capable, both intentionally and inadvertently, to make significant changes in the global climate and in the global ecosystem. We probably have been doing, on a smaller scale, things like that for very long periods of time. For example, slash and burn agriculture, which has been with us for tens of thousands of years, probably changes the climate to some extent by changing the albito of the period.

That massive changes have occurred is clear from historical record. For example, Egypt was once the breadbasket of the Roman Empire. That may be the same role as the American Midwest plays today. That is certainly no longer the case. It is not a greenhouse effect issue. You know it is more of a grazing issue, but it is an example of how humans are perfectly capable of making these unexpected and inadvertent changes.

Because the effects occupy more than a human generation, there is a tendency to say that they are not our problem. Of course, then they are nobody's problem. Not on my tour of duty, not in my term of office. It's something for the next century. Let the next century worry about it.

But the problem is that there are effects, and the greenhouse effect is one of them, which have long-term consequences. If you don't worry about it now, it's too late later on. So in this issue, as in so many other issues, we are passing on extremely grave problems for our children when the time to solve the problems, if they can be solved at all, is now.

If you ask what determines the Earth's climate, clearly, the main thing that determines it is sunlight. Sunlight is what heats the Earth. Not all of the light that arrives at the Earth from the Sun goes to heating the Earth. Some of it is reflected back. It is just the part that is absorbed.

What happens is there is a certain rate at which sunlight is absorbed by the Earth's surface, and there is a certain rate at which the Earth's surface radiates to space. What comes from the Sun is in the ordinary visible part of the spectrum that our eyes are sensitive to. What the Earth radiates into space is in the infrared part of the spectrum, longer waves than red, that our eyes are not sensitive to, but it is as legitimate a form of light as the kind that we are used to.

Now, if you calculate what the temperature of the Earth ought to be from how much sunlight is being absorbed, equally, how much infrared radiation would be radiated to space, you find that the Earth's temperature, by this simple calculation, is too low. It is about 30 degrees Centigrade too low. And why is it too low? It is too low because something was left out of the calculation. What was left out of the calculation? The greenhouse effect.

The air between us is transpiring, except in Los Angeles and places like that in the ordinary visible part of the spectrum. We can see each other, but if our eyes were sensitive, say, at 15 microns in the infrared, we could not see each other. The air would be black between us. That is because, in this case, carbon dioxide is very strongly absorbing at 15 microns and other wavelengths in the infrared.

Likewise, there are parts of the infrared spectrum where water absorbs where we could not see each other if we were only as far apart as we are in this room.

If you add these infrared absorbing gases to a planet, then what happens is the sunlight comes in as before, but when the surface tries to radiate the space in the infrared, it is blocked; it is impeded by the absorbing gases, and so the surface temperature has to rise so that there is an equilibrium between what goes in and what goes out.

So this is the greenhouse effect. It is a misnomer for more reasons than one. It is a misnomer because that is not how forest greenhouses work, but that is a very minor point. There are other gases which absorb in the infrared, all of the many of which have been mentioned already, methane, the halocarbons and these are products, partly of the agriculture. It is fertilizers, refrigeration, aerosol spray guns and so on, all products of our technology.

We don't generate much water into the atmosphere, but we certainly do generate a great deal of carbon dioxide through the burning of wood and fossil fuels, and apparently, benign activity. Who could object to humans burning oil and coal, gas and oil?

I would like to stress that the greenhouse effect makes life on Earth possible. If there were not a greenhouse effect, the temperature would, as I say, be 30 degrees Centigrade colder and well below the freezing temperature of water if we were on the planet. The oceans would be solid after awhile.

A little greenhouse effect is a good thing, but there is a delicate balance of these invisible gases, and too much or too little greenhouse effect can mean too high or too low a temperature.

Here we are pouring enormous quantities of CO_2 and these other gases into the atmosphere every year with hardly any concern about its long-term and global consequences.

Certainly, not all aspects of how increased CO_2 and other gases into the atmosphere affect the climate are known. There are so many uncertainties, although the overall picture is in quite a clear and widely understood and accepted. But there are questions about aerosols, about clouds. You heat up the Earth. How much increase or decrease in cloudiness is there? How does that change the albito or reflect to the Earth. There is questions about the ocean and its response in time to an increase in CO_2.

There are feedback effects. Therefore, it is certainly worthwhile to spend some additional money on further research on the subject.

Another point is that the significant temperature changes on the Earth between ice ages and pseudo-ice ages, glacial and interglacial time periods seems to be connected with quite small time changes in amount of sunlight that reaches the Earth due to changes in these orbital properties.

That is a suggestion that the Earth's climate system may be very delicately dependent on the sorts of factors that we are talking about here. That is why it makes sense to study past climatic change on the Earth as an attempt to obtain some caliration.

Another source of calibration is the other planets. Every planet with an atmosphere has some degree of a greenhouse effect. The most spectacular case, by far, is the greenhouse effect of Venus. It is the nearest planet; heated by the same mass, density, as the Earth, but it is spectacularly different in several respects, one of which is that the surface temperature is about 470 degrees Centigrade, 900 degrees Fahrenheit, and that enormous temperature is not due to its being closer to the Sun, because being surrounded by bright clouds, and, in fact, because it reflects so much light back to space, if that is all is happening, it would be cooler, not warmer, than the Earth.

The reason for this absurd high temperature on the surface of Venus, which is well understood—I mean, Soviet spacecraft have landed on Venus and, in effect, stuck out a thermometer. There is no doubt that the surface temperature is that high, and later U.S. spacecraft, as well.

The massive greenhouse effect is because CO_2 plays a major role. The amount of CO_2 in the Venus atmosphere is much larger than here. The atmosphere is almost entirely carbon dioxide, and there is 90 times more of it there than here. But it is an indication of what can happen in an extreme case.

You look at Mars or Jupiter or Titan, the big lumin Saturn, and you have additional examples of greenhouse effects, different gases, different amounts of sunlight reaching the surface, different planetary albitos and cloudiness. In all those cases, there is also a greenhouse effect.

In addition, it has been possible to calculate those greenhouse effects fairly accurately, so that the kind of theoretical armamentarium which is used to calculate the greenhouse effect, the greenhouse effect changes on the Earth, is also used for other planets, and therefore, can be calibrated to some extent against those other planets. If we keep coming up with the right answer in all those other cases, then probably, we understand fairly well how greenhouse effects work.

It would, however, be worthwhile, and along the lines that Senator Gore was talking about, to have an increased program through NASA to understand the greenhouse effects on other planets. This might be a very practical application of planetary exploration.

As you have heard, the best estimates, which certainly have some uncertainty attached to them, are at the present rate of burning of fossil fuels, present rate of increase of minor infrared absorbing gases in the Earth's atmosphere, that there will be a several Centigrade degree temperature increase on the Earth, global average, by the middle to the end of the next century.

And that has a variety of consequences, including redistribution of local climates and to the melting of glaciers, an increase in global sea level. There is concern on a somewhat longer time scale about the collapse of the West Antarctic ice sheet and a general rise of many, many meters in the sea level.

So we have a kind of handwriting on the wall. Certainly, there is more research to be done, but as I say, there is a consensus.

What can be done about it? The idea that we should immediately stop the burning of fossil fuel has such severe economic consequences that no one, of course, would take it seriously. But there are many other things that can be done. One has to do with subsidies for fossil fuels. More efficient use could be encouraged by fewer governments subsidies. Second, there are alternative energy sources, some of which are useful, at least locally. Solar power is certainly one that might be of more general use; safe fission powerplants, which are, in principle, possible; and then on a longer time scale, the prospect of fusion power, fission and fusion powerplants, in principal vent no infrared active gases, and therefore, would have other problems. They do not provide a greenhouse problem.

I would like to close by just saying a few words on the kind of perspective that this problem, as related problems, poses to us. Here is a problem which transcends our particular generation. It is an intergenerational problem. If we don't do the right thing now, there are very serious problems that our children and grandchildren will have to face.

It is also a global problem. It is no good if just one or two major industrial nations take major steps to prevent a major increase so furthering of CO_2 and other greenhouse gases, because other nations may, through their industrial development, cause the problem by themselves.

Not to say that this is inevitable, but to give an example, the largest coal reserves on the planet are the United States, Soviet Union, and China. China is undergoing a very major industrial development, and the burning of coal is certainly something that must be very attractive for the Chinese to look into the future.

I would say that there is no way to solve this problem, even if the United States and the Soviet Union were to come to a perfectly good accord on this issue without involving China and many other nations that will be developing rapidly in the time period we are talking about.

So here is a sense in which the nations to deal with this problem have to make a change from their traditional concern about themselves and not about the planet and the species, a change from the traditional short-term objectives to longer term objectives and would have to bear in mind that in problems like this, the initial stages of global temperature increase, one region of the planet might benefit while another region of the planet suffers, and there has to be a kind of trading off of benefits and suffering, and that requires a degree of international amity, which certainly doesn't exist today.

I think that what is essential for this program is a global consciousness, a view that transcends our exclusive identifications with generational and political groupings into which, by accident, we have wandered. The solution to these problems requires a perspective that embraces the planet and the future, because we are all in this greenhouse together.

Thank you, Mr. Chairman.

Senator **Durenberger**. Thank you very much, Carl. I'm just a bit frustrated on international amity. Some of us made a brief trip in August through Sweden, Switzerland, Germany, the Netherlands, and Poland and we are concerned about acid rain and its consequences. As I went, the urge in me for some forum for international amity would keep crying out, particularly when I got to Poland—which is the home place of my mother's side of my family—and to see the selfdestructiveness of that economy and the lack of amity on the part of the Czechs, on the part of the East Germans, is a frustrating experience. All of you must experience it every day of your lives, and I hope there is an answer in something other than legislation.

But it is your concerns, and those of many of us who are familiar with some parts of this and related problems, have to somehow take this place beyond an amendment to require that the United States contribution to the United Nations to be no greater than the contribution of the Soviet Union, and to somehow lift the people that claim a right to a place in the U.S. Senate beyond that kind of a view of the world, and lift it up somewhere closer to the real issues that affect people. I want to say that after listening to your comments.

Let me ask you, and then I intend to ask the other witnesses this, and that is whether the following is an accurate summary of the current state of our knowledge on this subject. For the first time, there is international scientific consensus that global warming can and will occur.

Second, while there are still uncertainties surrounding these predictions, it runs in both directions. That is, while global warming could be less than expected, it could just as likely be much worse.

Third, all predictions are based on the assumption that a new manmade atmosphere will behave in the same way as a natural atmosphere in the past.

Four, global warming is serious in itself, but there is also a symptom of massive perturbation of the natural physical and chemical processes.

And fifth, relatively painless actions could be taken which would slow the warming trend; for example, the use of CFC's and spray cans will be banned throughout the world.

Cars and trucks could be required to meet stringent carbon monoxide standards such as those in the United States, again, depending on our international amity.

Is that a fairly accurate summary of the current state of our knowledge?

Dr. SAGAN. The only statement in there that I would have some quibble with, is the one which goes that the scientists are assuming that the atmosphere, with the increased infrared absorbing gases, that it will act the same as the present atmosphere. I don't believe there is any such assumption. The calculations have such principles. But apart from that, what you read seems principled.

Senator DURENBERGER. You were invited to testify because you are something of a scientific generalist, and one of your best qualities is the ability to explain complex scientific issues in a way a layman can understand. You have often worked on a variety of these issues.

One scientist who recently worked in this field was asked why he was devoting so much time and attention to it, when there seemed to be more urgent problems, and his response was that in his opinion, climate alteration was the most serious problem to man, short of peace for the world.

Those seem like strong words, even with a person who has committed his entire life to the problem. You are more of a generalist than the person I am quoting. You have spent time considering the implication of other threats, including the nuclear winter. In the context of potentially cataclysmic events, how would you score climate alteration?

Dr. SAGAN. I recognize the need for a rank order of catastrophes so we know which ones to devote our attention to first. But I would hope that we could concentrate on several potential catastrophes at the same time.

Senator DURENBERGER. Which two or three?

Dr. SAGAN. I certainly agree with your anonymous informant that nuclear war is far and away, heads and shoulders, the most dangerous threat to the Nation and the world, possibly the human species.

I also agree that the sort of climatic effects that we are talking about today are very serious because they have global purview and because they are so intimately tied to something which we are so reluctant to give up for clear economic and other reasons, the wood burning and fossil fuels.

In 1945, after the first nuclear explosions, Einstein said that everything had changed except our way of thinking, a remark that certainly is still appropriate today and I think is applicable to this particular issue.

That is what I was trying to discuss in my testimony, that there is a kind of global and intergenerational thinking that is essential for dealing with these problems, the nuclear war issue, as well, and other candidate catastrophes like AIDS and other new epidemic diseases, all of which cannot be resolved except on an international global basis.

The eradication of smallpox, for example, to take a successful example, was done at the expenditure of tens of millions of dollars by a planetary effort, by the medical community, to use an example, of a problem that certainly was considered very difficult some thousand years ago, that is now completely gone. There are no more cases of smallpox on the planet.

So it is a reminder to us that these problems can be solved, but not if we persist in keeping to our narrow frames of interest in space and time.

Senator DURENBERGER. OK.

Max.

Senator BAUCUS. Dr. Sagan, a lot has been written, and a lot of people have spoken about some of the effects of increased carbon dioxide and other gases. Are there any benefits? That is, one can argue that in some of the colder climates of our country, warmer temperatures would help.

Dr. SAGAN. Just coming from upstate New York, I know what you mean, Senator Baucus.

The distinguished scientists who will follow me on this panel would be better qualified than I to answer that question, but it is clear that increased carbon dioxide, for many planet species, produces a more luxuriant growth. That is true both of crops and of wheat, but that might be considered a benefit. Also the one that you just talked about. There are places that are cold which would be happy to be warmer. There are places that have a moderate climate that will be unhappy about being warmer, and that is that balancing out of pluses and minuses I was talking about before.

But I don't think anybody will be happy about the inundation of all the coastal cities on the planet except, I suppose, the people who live on the new coast lines who will be delighted to have coast traffic.

Senator **Baucus**. Is there any difference of opinion at all within the scientific community over this trend? That is, with increased carbon dioxide and other gases building up, that by sometime next century, say, the year 2075, or 2080, that the overall temperature will have increased *x* number of degrees Fahrenheit?

Dr. **Sagan**. I would defer to Dr. Manabe and others on this, but if you look at the 1982 National Academy report—I forgot the exact title—"Climatic Effects of CO_2, a Reassessment," something like that, they talk about a few dissenting scientific papers, and that is a few scientists who say that the effect is not nearly as severe as has been widely advertised and the Academy's report gives a very succinct explanation about why these studies are inaccurate.

Senator **Baucus**. So, it is your judgment that the vast preponderance of thinking in the community is in accordance with what you are saying?

Dr. **Sagan**. Yes.

Senator **Baucus**. What is the best international arena within which to address some of these problems? I mean, do we have to create a new forum or organization? Should we work within some existing organizations? Do we deal with this on an ad hoc basis? What guidance can you give us, in your thinking, as to how to get other countries; A, to think about this, including this country; B, how to work in some cooperative, constructive basis?

Dr. **Sagan**. It seems to me that the situation has to be arranged so that everyone benefits and that a developing country that is being asked to forego readily available supplies of fossil fuels has to be given something of value in exchange, and if we develop fusion powerplants that are effective, for example, then it seems to me there has to be——

Senator **Baucus**. I wondered if you had given any thought to the process in addition to the information and the substance.

Senator **Durenberger**. Carl, before you go into that, I am going to have to break and go over to vote. I want to express my appreciation to you for being here today on behalf of all of us and for those who were not able to be here.

Senator **Baucus**. We are both going to have to vote.

Senator **Durenberger**. I have got to go vote.

Dr. **Sagan**. OK. I didn't have a good answer, anyway.

Senator **Baucus**. You have about 15 minutes to think of one.

Senator **Durenberger**. We will recess the hearing. Thank you very much for coming.

[Recess.]

Senator **Durenberger**. The hearing will come back to order. Undoubtedly, it is going to be disrupted again. We, overnight, discovered 41 amendments to the continuing resolution. The Senate has once again risen to the occasion.

Our next group of experts will constitute a panel that will consist of Dr. Ralph J. Cicerone, the director of the Atmospheric Chemistry Division of the National Center for Atmospheric Research. Ralph, come on up and tell us the last time you remember having hay fever.

Dr. Syukuro Manabe, Geophysical Fluid Dynamics Laboratory from the National Oceanic and Atmospheric Administration; Dr. Gordon J. MacDonald, vice president and chief scientist, MITRE Corp.

I meant to ask you this: Are you related to the Mr. MacDonald we keep hearing about up here?

Dr. **MacDonald**. No.

Senator **Durenberger**. OK. We also have Dr. Dean Abrahamson, who is a professor at the Hubert H. Humphrey Institute of Public Affairs, the Environmental Committee on Research Energy and Policy, director of the Institute of Local Environmental Policy Projects and is an advisor to the Royal Institute of Technology in Stockholm.

We welcome all four of you, and your statements will be made a part of the record. We will proceed with Dr. Ralph Cicerone.

STATEMENT OF DR. RALPH J. CICERONE, DIRECTOR, ATMOSPHERIC CHEMISTRY DIVISION, NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

Dr. **Cicerone**. Thank you, Mr. Chairman, for the invitation to be able to speak with you on this issue. With your permission, I would like to attach four technical appendices to the material I am submitting to you today.

Senator **Durenberger**. Without objection, that is appropriate.

[The appendixes referred to by Dr. Cicerone have been retained in committee files.]

Dr. **Cicerone**. Also, with your permission, I would like to paraphrase and jump in and out of my written testimony to try to go as quickly as I can.

Senator **Durenberger**. Fine.

Dr. **Cicerone**. My main point today will be to try to summarize other information we have for you about other gases besides carbon dioxide, whose effects are additive from the point of view of the energy balance of the Earth, that is, additive in the direction of warming. I will describe some of the properties of those substances, what we know about them, and a few things we don't know. I will try, in my own words, to give you an idea of the dimensions of the global issue that we are looking at, namely, that the forcing of this radiation on the Earth's energy system is unprecedented in recorded history and probably of the same proportions that has caused interglacial warming.

Dr. Sagan has already spoken about the atmospheric window, which is a peculiar property of the gases in the air today; that there is a region of wavelengths between about 7 and 13 micrometers wavelength, where the air is really relatively transparent.

This window has been known theoretically, based on the properties of the chemicals in the air, what we can measure in the laboratory, but its existence is also proven from satellite measurements looking down on the Earth and other ways of observing the atmosphere. This is not a hypothetical phenomenon. Its specific importance is that over 25 percent of the radiation escaping the Earth and a much higher fraction from the top of the atmosphere leaves through this window region, so that if one were trying to change the Earth's climate intentionally—to take that point of view—one would have to look for leverage of that sort or the type that Dr. Sagan mentioned, changing the reflective properties of the Earth's surface by changing land use patterns, for example, from forest to deserts.

A powerful lever we have over the Earth's climate is this atmospheric window region. Well, how would one go about trying to change the energy balance of the Earth?

In my testimony, I point out that all the energy usage on an annual basis by humans is less than one ten thousandth of the rate at which energy reaches us from the Sun. Just to give you an idea of the magnitude, we couldn't go out and simply burn things and try to make the air warmer. The numbers don't add up. The window region of wavelengths gives us this leverage. What are the properties of chemicals that can work toward that task? We need chemicals, if one were to try to do this now, that absorb radiation in that special wavelength region rather strongly and which don't overlap with wavelengths that are already well absorbed.

Dr. Sagan gave us a graphic description of air looking black at 15 micrometers; you wouldn't want to waste your absorbers on wavelength regions that were already absorbed. You would look for chemicals that absorb in between, in that window region.

Second, I would look for chemicals that can last once they are out of the atmosphere. Why do you want the chemicals to last? So that you can use just a pinch of them to get some leverage, so that you can pick up reasonable concentrations in the air with relatively small input amounts of chemicals and so that global coverage could be attained, so that, for example, the chemicals released in Stockholm can survive a matter of 1 or 2 years to make there way to the Southern Hemisphere as fluorocarbons do.

That is what we are dealing with, with many of these other gaseous chemicals, and the ones I would list briefly today are several fluorocarbons and chlorocarbon gases that are synthetic: Nitrous oxide, which is laughing gas; a rather natural chemical, really, methane, which also has some of its presence due to natural activities, and ozone in the lower atmosphere.

Of those, chlorofluorocarbons stand out in several ways. First of all, they are the longer lived. Some of them are now proven to be able to exist in the air once they are airborne for over 100 years; others, in tens of years; a couple of them, in multi-hundreds of years. Their sources are the easiest to understand, because they are synthetic.

We know where they are coming from; We know why they were invented; where they were invented; where they are produced; in what quantities; how they are used; how the usage patterns are changing; that the United States initially was responsible for more than half of the production, usage, and applications of these chemicals, but that fraction is now well less than half due to the adoption of these very useful chemicals worldwide for a number of applications, such as refrigeration, as well as aerosol propellants and solvent usages, specialty applications, foam blowing, and so forth.

We now know that those chemicals are building up in the atmosphere. The rate of increase has slowed down to about 5 percent per year increases, so that on a percentage per year basis, these chemicals are building up faster than any of the other ones that were mentioned, including carbon dioxide.

Their concentrations are the lowest of all the ones we speak of, but their infrared absorbances are very high, indeed.

In the case of nitrous oxide, we are really unsure as to why it is increasing, but we know that it is increasing in concentrations globally at a rate which sounds rather small, only about a quarter of a percent per year. If you think in terms of inflation, economic inflation, that is a small number. But what is interesting about nitrous oxide is that that very small rate of increase tells us that the whole global nitrogen cycle, involving nitrogen-nutrient cycling globally may be rather strongly out of balance. We can prove that even at that small rate of increase, it tells us that whatever the sources of nitrous oxide are, they are about 25 percent higher now than the unperturbed natural sources.

We think that the two candidates for the nitrous oxide increases are combustion of nitrogen-rich fuels and the microbiological transformations of nitrogen fertilizer applied in agricultural settings, both nitrification and denitrification of nitrogen fertilizer.

Atmospheric methane is, I think, more dramatic and more vexing right now than the others, because its sources are not very well quantified. But we know that atmospheric methane molecules last about 10 years each in the air. That residence time, along with knowledge of the global atmosphere methane amounts tells us immediately the total of the methane sources, even if we don't understand which individual methane sources are most responsible for the total measured rate of increase of over 1 percent per year globally.

The key candidates that we believe are forcing this methane increase are increased rice agriculture; multiple cropping which, of course, keeps the soil underwater perhaps 8 months a year instead of 4; increased population of ruminant animals; increased rates of biomass burning, mostly tropical forest clearings for agriculture; increased coal mining, mineral exploration; natural gas transmission, and mining. All of these activities result in more methane in the atmosphere.

We also have another logical possibility which is a live one right now: That something is changing in the chemistry of the global atmosphere, which is decreasing the atmosphere's ability to assimilate these otherwise normal entries of methane into the atmosphere every year. It is the OH gaseous radical, a kind of fragment of a water molecule, in the air, that we believe is responsible for destroying methane naturally in the air, and there are indirect indications now that atmospheric OH is decreasing under the influence of human activities. These changes occur through some very complicated atmospheric chemistry that we have just begun to understand.

I would like also to mention atmospheric ozone, because the complications of atmospheric chemistry really confront us here. We know that atmospheric ozone is decreasing in the upper stratosphere. It appears to be increasing in the lower stratosphere. That is above the weather systems, and it also appears to be increasing where it is a most potent greenhouse gas, in the troposphere of the Northern Hemisphere, the region of atmosphere closest to us.

We believe the increase is due to anthropogenic nitrogen oxides and hydrocarbon gases, but the quantitative information is quite lacking here, so that predictions of future trends are very difficult.

I have covered a lot of this material in the four technical appendices which I have contributed.

I would like to close by just trying to describe the dimensions of these effects a little more clearly.

I think we have been focused too much on a doubling of carbon dioxide as the only thing to be concerned about.

There will be climate effects which will probably be distinguishable by scientists and felt by humans. Even before there has been a doubling of carbon dioxide. That is certainly before the middle of the next century.

The time lags, of course, have to do with oceanic uptake and several other phenomena that have already been discussed. But the added radiative forcing of these other trace gases will lead to climatic effects earlier than if we simply were to wait for carbon dioxide to increase.

There is no recorded information on or any even theory that says that the Sun has changed enough in the last 100,000 years, in any sustained way, to alter the energy balance as much on the income side as these trace gases are already doing on the output side.

I think that should give us pause for concern that natural variability of the Sun is smaller than the force that is being contributed by humans now.

And I have already mentioned the size of the total effect of carbon dioxide and the trace gases in decreasing the outgoing energy to space.

Senator **Durenberger**. I am going to have to interrupt you and go over and vote.

Dr. **Cicerone**. That is the end of my statement.

Senator **Durenberger**. Thank you very much. My apologies to the witnesses.

[Short recess.]

Senator **Durenberger**. The hearing will return to order and to the testimony of Dr. Manabe.

I appreciate your being here. Your full statement will be made a part of the record.

STATEMENT OF DR. SYUKURO MANABE, GEOPHYSICAL FLUID DYNAMICS LABORATORY, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Dr. **Manabe**. Thank you very much for giving me an opportunity to appear here to testify on the climate warming issue. I work for National Oceanic and Atmospheric Administration of the Department of Commerce.

One of the most powerful tools for the study of climate problems is mathematical climate model. It consists of a system of the equations which represent the laws of physics governing the behavior of atmosphere and the oceans. The atmospheric component of such a model resembles a numerical weather prediction model which has been used successfully by the weather service of United States and many other countries. "Computer guidance" used by TV weathermen is obtained from this type of model.

We have known that this kind of model can mimic the behavior of the atmosphere and oceans and can simulate very well the geographical and seasonal variation of the climate. Encouraged by the success in climate simulation, we have used this model for a wide variety of climate problems, including the problem of climate warming due to the increased greenhouse gases.

As already noted by previous speakers, an international conference of experts was organized jointly by the United Nations Environmental Programs, the World Meteorological Organization, and the International Council of Scientific Union in order to discuss the climatic effect of the increased greenhouse gases and its associated impact. I was one of the participants of this meeting.

The executive summary of the conference report concludes that if present trends continue, the combined concentration of carbon dioxide and other trace gases in the atmosphere would be radiatively equivalent to a doubling of carbon dioxide from preindustrial levels, possibly as early as the 2030's. In other words, the CO_2-equivalent of greenhouse gases will double from the industrial value approximately 40 or 50 years from now. This was discussed earlier by Dr. Cicerone. Based upon the examples from the most advanced climate model, the report states that such an increase of greenhouse gases would raise the global mean surface air temperature between 1.5 and 4.5 °C—or 2.7 and 8.1 °F—confirming the earlier statement made by the U.S. National Academy of Science. The report cautioned, however, that the value outside this range cannot be excluded because of imperfections in climate models. Due to the thermal inertia of oceans the warming would be delayed further by several decades. Nevertheless, it is highly likely that the global mean warming of about 3 to 8 degrees Fahrenheit will be reached in the second half of the next century if the present trends in the increase of greenhouse gases continue. The report noted that such a climate change would have farreaching impacts on human life and the planet's ecosystem.

At the Geophysical Fluid Dynamics Laboratory of NOAA, my colleagues and I have been working on this problem for the past 25 years. You wonder why you spend such a long time on this problem? It is a very painstaking, long-term process to improve these mathematical models.

One of the results obtained from the model experiments conducted at our laboratory and other institutions is that the climate change due to the increased greenhouse gases is not uniform geographically. The surface warming is particularly large in high latitudes during winter, making the winters less severe in Canada and the Soviet Union.

One of possible consequences of increased greenhouse gases is a reduction of the sea ice coverage over the Arctic and the Circumantarctic Oceans. In the tropics, warming would be smaller, but as you know, the tropics is already hot enough, so I don't know whether that is any consolation to us.

It is expected that increases of greenhouse gases will also affect the wetness of the continental surface and the hydrologic cycle. Because of the penetration of warm, moisture-rich air into high latitudes, a doubling of atmospheric carbon dioxide or equivalent might increase the rate of river-runoff over Northern Canada and Siberia by 20–40 percent. This probably has an import practical implication.

Our climate model also indicates that, in response to the increased greenhouse gases, summer drought will become more frequent over the middle continental regions, of North American and the Eurasian continent. For example, the model-produced summer drought is characterized by dry soil, reduced cloud cover and higher surface air temperature, which resembled the situation during the Dust Bowl period of the 1930's, when the Northern Hemisphere's average mean temperature was significantly above the normal value.

This picture illustrates, for the June–July–August period, the percentage change of soil moisture induced by a doubling of carbon dioxide. The reddish or brown-red area indicates the area where soil moisture reduces more than 20 percent. In view of the limitation of current climate models, you should not take literally every small scale features in this map. Nevertheless, this figure shows that soil moisture reduces substantially over Great Plains of North America, Western Europe, Northern Canada, and Siberia during summer.

Why? One of the important mechanisms responsible for this summer reduction of soil wetness is as follows. As you know, the rate of river-runoff is very large and soil is very wet in the Midwest in the late spring. After the termination of the snowmelt season, sunshine increases, and the absoption of solar energy by continental surface increases. Thus, the evaporation from the surface is enhanced. Accordingly, the continental surface dries from the spring toward summer.

Now, in a CO_2-rich, warm climate, the snowmelt season ends earlier. Thus, the spring to summer reduction of soil wetness described above begins earlier, making soil dryer in summer. The other mechanisms are a little more difficult to explain.

Another reason for the reduced soil wetness is that the spring rainy period ends earlier, again making soil drier in summer.

The mid-continental summer drought described above results from the surface warming which increases with increasing latitude. However, it does not depend critically upon the details of the pattern of the warming.

Major uncertainty remains, as pointed out by earlier speakers, in estimating climate change due to the increase of the greenhouse effect. For example, it is difficult to estimate with confidence the delay in climatic response due to the thermal inertia of oceans. This is because the oceanic component of a climate model is at an early stage of development. The model uncertainties are also due to our inability to model accurately the interaction between cloud cover and radiative transfer in the atmosphere. Currently, oceans and cloud cover are two of the subjects selected for intensive research in the World Climate Research Program.

Senator **Durenberger**. You get me very interested when I see the possibility that in the Red River of the north, the Agasea Basin, the 35-mile radius, in the wheat heart of North Dakota and Minnesota, that we might not have floods. But then it bothers me that we might have more than 5 tons per acre of soil blowing from one State to the other because it is drier and drier, and the wheat basket, both in our country, and in central Europe, and we also lose it in the Soviet Union.

Dr. **Manabe**. One thing, however, you have to remember is that it gets wetter in the winter.

Senator **Durenberger**. Wetter in winter?

Dr. **Manabe**. In winter, in our model. The model indicates wetter in winter. This is something to consider in the development of the strategy for water management

After listening to my presentation, you may wonder whether the climate may have changed already due to the past increase in greenhouse cases. This is the natural question you would ask. The report from the Villach conference noted that the global mean temperature has increased by about 0.3 to 0.7 degrees centigrade, which is about 0.5 to 1.3 degrees Fahrenheit during the last 100 years. This is consistent with the warming expected from the model calculations. However, the report pointed out that this past warming cannot be proven to be caused by the increase of greenhouse gases in a scientifically rigorous manner. This is because of the lack of reliable information on the past variation of the factors that causes climate changes. These factors include solar irradiance and stratospheric loading of aerosols.

To detect the future change in climate due to greenhouse gases, it is imperative that we monitor the basic variant describing climate as well as factors that can cause change. These measurements require sustained and serious commitment on the part of this country.

In addition, the real progress will require increased levels of international scientific cooperation in monitoring and modeling of climates. Thank you.

Senator **Durenberger**. Thank you very much Dr. MacDonald.

Dr. MacDonald, your statement will be printed in the record.

STATEMENT OF DR. GORDON J. MacDONALD, VICE PRESIDENT AND CHIEF SCIENTIST, MITRE CORP.

Dr. **MacDonald**. Thank you, Mr. Chairman.

My assignment this morning is to discuss the biological and oceanic consequences of increasing carbon dioxide. In looking at this problem, there are considerations as to whether or not the oceans can ameliorate possible climate change and how the plant systems of the world will react as the carbon dioxide content increases and climate adjusts in the manner described by the previous speakers.

There are two kinds of effects that one is concerned with. First, there is the direct effect of carbon dioxide increase. As carbon dioxide concentration in the atmosphere increases, some fraction of it will dissolve in the ocean. Similarly, as carbon dioxide increases, a wide variety of plants, not all, but many, increase their productivity.

In fact, of the total amount of carbon dioxide being released into the atmosphere, only about 45 percent remains in the atmosphere. The other 55 percent is sequestered either in the oceans or the biosphere; we are not certain which. This is one of the large uncertainties that remains in this problem. What we do know is that that fraction has remained more or less constant since 1958, when the first detailed observations of the carbon dioxide concentration of the atmosphere were made.

There is a much more difficult question concerning the indirect effects. That is, as climate changes and the atmosphere warms, some of that warmth will be transmitted to, and will warm the oceans. In fact, the oceans can act as a moderating influence on the warming by absorbing some of the heat that otherwise would go into further warming the atmosphere.

But as the oceans warm, carbon dioxide is driven out of them, and you have the possibility of what is commonly called a positive feedback. That is, as you increase the temperature you drive more carbon dioxide out of the oceans, increasing the temperature to a greater degree, and so forth.

But ocean circulation is a very complex matter, and as Dr. Manabe pointed out, modeling of the oceans is nowhere nearly as sophisticated as that of the atmosphere, despite, I might say, the very heroic efforts of Dr. Manabe and his colleagues in trying to bring the oceans and atmosphere to terms, at least as far as the computer models are concerned.

Just to give you a flavor for this kind of complexity, the ocean circulation is largely controlled by the sinking of cold water in the Norwegian Sea, the Labrador Sea, and to some extent, the Weddell Sea and Antarctica. This cold water sinks, penetrates to some depth within the ocean, and follows a meandering path, on the average, to rise several hundred years later.

As it disappears to depth, it carries with it some of the heat and some of the carbon dioxide. A real problem, and one which is not clearly understood, is how that process is going to be disrupted or changed as climate conditions alter the world over.

Similarly, the response of biological communities to changing climate, the indirect effect of increasing CO_2, is highly complex. The best we can do at present is to look at historical data, and again, to give you a flavor, and I select the Red River Valley for obvious reasons of the membership of this committee, there, spring wheat is a major crop. One can make an estimate that says that a 1 degree centigrade rise in temperature leads to an increase in the growing season of about ten days.

Coupled with this warming, as Dr. Manabe illustrated, there will be drier conditions. The direct effect of lengthening the growing season can be anticipated—and you can check it by looking at the historical records—to increase wheat productivity.

On the other hand, there will be a higher frequency of very warm days in June and July when the spring wheat grows, and during these infrequent times, the hot spells will reduce productivity. In fact, the best estimate today would be that if you had a 1 degree rise in temperature in the Red River Valley, and a 10 percent decrease in precipitation during the summer time, that the productivity of the wheat would decrease approximately 10 percent in yield.

Now, this is just one example. There will be different responses in different areas. And as I say, this example is drawn purely from historical data and would not allow for larger range excursions.

In looking at the long-term effects of climate on agricultural productivity, on water resources, and on those aspects of our society that form the base for our economy, we have to ask three related questions: With the warming, will there be a greater effect in winter or in summer? What will be the effect during daytime versus night? What will be the impact on the extreme variations; the periods of drought, the periods of early frost, the storminess, the frequency of hurricanes?

To the first question, Dr. Manabe and his colleagues have indicated that yes, the seasons will differ; winter will tend to be warmer. The day-night issue is very much a mystery. To my knowledge, it has not yet been adequately dealt with.

The question of extremes in climate remains almost a total unknown. The best that can be done is to argue by analog. This is an imperfect argument, but it says that if you have complex systems that undergo changes in which the equilibrium state is changed—and here we are changing the state at which the atmosphere would arrive continually, as gases are added to it—that the fluctuations, the highs and the lows, will become more extreme, and that this greater noisiness of the weather can be anticipated to come, perhaps, long before you see the large shifts in average conditions.

Now, given these uncertainties, what are some steps that might be taken? I have selected four items that indicate the kinds of issues on which governmental action could exercise some leverage of the longer term problem.

Fuel efficiency standards for automobiles and light duty trucks are a subject that has recently received some attention. As you loosen the requirements on fuel efficiency, you will use more energy. You will also produce greater amounts of carbon monoxide and oxides of nitrogen, in total, even though their standards are mandated, and thus increase the effect of other trace gases referred to by Dr. Cicerone.

A second area for which the Environment and Public Works Committee has direct responsibility concerns the Clean Air Act Amendments and various proposals to deal with acid rain. The chemistry of the atmosphere is involved in problems of climate change. It is also involved in problems of acid rain, and I have prepared for the committee a paper detailing these links. [The paper referred to has been retained in committee files.]

Just as an illustration, one of the climate changing gases is ozone. Ozone is a very strong oxidant and reacts with sulphur dioxide in the atmosphere to convert it to sulphuric acid, part of the acid rain phenomena.

Reducing sulphur dioxide, by itself, as an isolated action, might have the impact of increasing oxidant levels. Those increased oxidant levels would worsen the acid rain problem, and oxidants themselves may be responsible for damage that is generally attributed to acid rain, the damage of forests, the damage of that sort.

I believe that in looking at the Clean Air Act and at future amendments to it, in looking at acid rain proposals, the issues related to climate change have to be integrated and considered concurrently.

A third area is environmental impact statements. I have almost a nostalgic view of this bureaucratic monster that was created some 15 years ago. The environmental impact statements were, in large part, designed to alert decisionmakers of possible adverse effects that could take place through proposed governmental action.

As a one-time avid reader of these statements, I do not recall the climate impacts as an element in the considerations. For example, in considering the relaxation of the fuel efficiency standards for automobiles, the climatic impacts were nowhere considered.

Finally, I believe that research, a topic addressed by Dr. Sagan, is clearly an area which needs far more attention, and I was much taken by Senator Gore's proposal to focus attention on this through an international carbon dioxide year. I have perhaps broadened the Senator's concept: It is the year of the atmosphere, but attention should be focused on those elements of research that will reduce uncertainty as to what will happen in the future.

The uncertainties will always be there. We will never be able to predict with perfect confidence. On the other hand, we can reduce those uncertainties that exist at present, such as what is the role of the biosphere, and what are the roles of the oceans in dampening or perhaps accelerating climate change?

In closing, I would like to compliment the chairman and the committee for holding these hearings. I think this issue is of comparable importance to any issue in the long term, with the obvious exception of nuclear war. I think we need to keep the awareness of this issue at a high level, and discussions of this sort certainly contribute to that goal.

Thank you, Mr. Chairman.

Senator **DURENBERGER**. Thank you very much.

Dean **ABRAHAMSON**. Welcome.

STATEMENT OF DR. DEAN ABRAHAMSON, HUBERT H. HUMPHREY INSTITUTE OF PUBLIC AFFAIRS

Dr. **ABRAHAMSON**. Thank you. Thank you, Mr. Chairman, Senator Gore. I would like just to have permission to introduce the Villach Conference statement into the record.

Senator **DURENBERGER**. Without objection, it is so ordered. [See p. 97.]

Dr. **ABRAHAMSON**. And to extend the responses to questions a little bit. I have a sense we are not going to have time to explore all the details.

I was asked last night why I was bothering to spend time on this issue, and my response was that I think this is the major environmental and economic issue that we are confronting now, short of the nuclear war question.

What we decide to do about limiting temperature increases is going to have a major effect on virtually every aspect of our society, if not in our lifetime, certainly in that of our children.

My written remarks, and also what I say this morning, are cast around a scenario of a warming of 5 degrees Celsius—9 degrees Fahrenheit—I chose that number for a number of reasons:

One, I think that a warming of that extent within the next few decades is entirely plausible.

Second, it will have major impact.

Third, we know something about the climate response to forcing of that kind, and lastly, if we now vigorously undertake policy initiatives, we may be able to limit warming to 5 degrees. I don't think that anything much lower than that is realistic, unless we assume the most optimistic bound of scientific evidence and very rapid policy responses.

Rather than attempt a detailed accounting of impacts under such a scenario, let me note some impacts which seem likely.

Activities and resources which much of the present U.S. environmental legislation is designed to protect would be in jeopardy. In the Midwest and Far West a drier climate would influence the viability of forests and hence the viability of various national forests and wilderness areas. Reduced lake levels and stream flows would affect freshwater ecosystems, and, for instance, make the preservation of endangered aquatic species quite difficult. They would also make difficult adherence to present water quality standards, which would need to be tightened with less dilution of water-borne pollutants. In the north, warming and drying would threaten peat bogs, marshes, and prairie potholes, and the species dependent upon them for breeding grounds or habitat. On the coasts, a 2 meter rise in sea level would inundate most salt marshes and coastal wetlands, push barrier islands further toward the present coast, and contaminate coastal aquifers.

One could do a quick accounting of the ecological or environmental resources that would be affected, and it turns out to be quite long, including, for instance: endangered species; habitat preservation; coastal zone protection; all legislation affecting inland rivers and lakes, dams and water diversion; groundwater protection—hence concern over hazardous wastes; wind-driven soil erosion and desertification—and hence western Federal land management and reclamation. Given the scenario, most of the impacts would be negative, and, in the extreme, though still plausible, worst case, would undo much of the present effort at environmental preservation.

Economic activities that are temperature and moisture sensitive, for example agriculture, also would be affected. It is impossible to predict with any degree of confidence the yield impacts that are possible, given the many structural and technological changes which the agricultural sector is presently undergoing. However, present agricultural sensitivity to climate—as evidence in yield responses to heat waves and drought—strongly suggests that negative impacts would be registered. Much work needs to be done, but the available analysis suggests that a more sober view of the agricultural/forestry/grazing situation is in order than constitutes the present accepted wisdom.

So, for what activities is there a reasonable chance of negative impacts? A short, and admittedly incomplete list would include: grain, vegetable and animal agriculture; fiber production; any activities dependent upon in-stream rivers flows, for instance electricity and synfuels production, urban water uses, barge transport, and agricultural irrigation; many forms of recreation; coastal development, fisheries, and settlement patterns; and forest-related industries. Water scarcity in southern California, as well as fire incidence, would be of special concern upon realization of the 5 degree scenario. This concern stems from the very dense pattern of regional population, the size of which makes any major impacts—including outward migration of people—a significant national problem. The National Academy of Sciences suggests reductions in streamflows in the Colorado River and in the rivers of northern California of as much as 40 to 60 percent with only a 2 degree Celsius warming and 10 percent precipitation reduction. This study suggests considerable stress between anticipated demand and supply. From where will replacement water come? What will be the costs of movement? Can it be moved, and, if not, what are the implications? I do not know the answers to these questions, but simply suggest that they are a matter for no small national concern.

I think we could avoid a warming of more than a few degrees through a vigorous policy to increase end-use efficiencies, by reduction of the absolute levels of coal consumption, by the use of natural gas as a transition fuel, and a number of other realistic measures. Policies to achieve an energy supply and end-use structure that would result in limiting to, on the order of 5 degrees, exist. I think their implementation is realistic.

The next point is, I can't take much credence with talk about adaptation. The nature of the impacts, the societal response to the impacts, will depend not only on the amount the temperature changes, but the rate at which it does change. We are facing a temperature change greater than ever before experienced during civilized times, and a long time before that, taking place over a time that is short compared with lifetimes of either trees or people.

In terms of impacts and response, the rate of temperature change is at least as important as is the total magnitude of the change. We are talking about changes happening in short times with respect to social and economic timeframes.

The question was asked earlier this morning by one of the members, "When do we have to do something?" That question has to be answered in terms of the level you want to limit the damages.

I will argue that if you want to limit the temperature increase to something like 5 degrees, that if you begin now and are vigorous about it, you may be able to do that. Only under the most optimistic set of circumstances can a policy of "wait and see" still result in a temperature increase of less than 5 degrees. To defend "wait and see" you have to take the lower limit of the temperature sensitivity to a doubling of CO_2; you have to take a lower limit of the effects of the other greenhouse gases, and you have to take a lower limit of the inputs from the sources mentioned by Dr. MacDonald, namely, increased respiration as a result of warming, outgassing of CO_2 from the oceans as a result of warming.

But on the adaptation time, the lead times for the systems, for example, the hydrological systems suggested by Dr. Manabe, are long compared with the rate of change of temperature. To implement such adoptive mechanisms one needs rather specific regional information, and it has to be available with reasonably high certainty to support anticipatory planning.

By adaptation, I think people ordinarily mean planning for the change so that it will be relatively less disruptive. I think that is Panglossian to think about anticipatory adaptation to this issue.

On the other hand, I think we know enough now to justify, and to implement those measures which will delay and limit the temperature increase. Further, virtually every one of the measures not only suggested this morning, but that are in the literature, are justified on other grounds, as well. I think that things like improving energy efficiency are justified solely on the basis of the carbon dioxide problem. But there are many other reasons, and many other issues that will be helped at the same time.

Some specific policy recommendations: One, Dr. Macdonald mentioned incorporating global warming into the EIS process. I like that too, and there are now measures underway to encourage the Council on Environmental Quality to do the necessary rulemaking to require that climate change implications be included in the EIS process. That is not required at present. Hopefully, the Administration will respond.

Increasing auto efficiencies has already been mentioned, but I want to elaborate a little bit. Increasing auto efficiency will have multiple benefits.

First as has been already mentioned, it will directly decrease the use of noxious gases, carbon dioxide, and carbon monoxide. But more importantly, it will reduce oil consumption; it will reduce pressure on oil prices. It will tend to stablilize oil prices and thereby extend the oil resource, but perhaps most importantly, it will go a long way to discourage the shift to coal and to solid hydrocarbon-based synfuels.

Limiting the temperature increase to 5 degrees requires a reduction in coal use; it doesn't require a slackening of the growth rate; it requires an absolute reduction in coal use.

Some rather elegant energy policy work has been done over the last years, for example, by Dr. Williams and his colleagues at Princeton. This work shows that if coal is considered as the swing fuel to limit CO_2 and if we are going to limit CO_2 to 1.7 times preindustrial levels, which correlates roughly with our 5 degree scenario, then coal use must decrease in absolute terms about 20 percent before the year 2020 and continue the reduction at an expediential rate of about 0.6 percent per year thereafter.

We should encourage natural gas as a transition fuel and, of course, those measures to increase end-use efficiencies of energy generally.

The second recommendation is, to reinforce Dr. MacDonald stressing the importance of the biomass. Deforestation may be a major source of CO_2 although the evidence is not unequivocal. Deforestation is also associated with the production of a number of the other greenhouse gases. That has already been mentioned, but the whole biotic response is known with much less certainty than is the fossil fuel response. There are large pools of carbon that may be oxidized fairly rapidly with increasing temperature. The respiration rate increases about three-fold for every 10 degrees Celsius so for every degree increase, respiration rates increase by 20 to 30 percent.

Last, I think we need some pretty hard-nosed impact analysis, not only so that we know what we are facing and can justify the policy measures to limit it, but also to get some feeling of what sort of societal transitions there are going to have to be. The costs of the biotic work and the costs of the impact work, the policy analysis, are orders of magnitude less than the costs associated with satellite work, climate models, and such. Yet, evaluations of alternative policy responses, and gaining a better understanding of societal responses to global warming are probably now more important than improving the accuracy of the climate models. The climate models, and other evidence, are now sufficiently good to show that policy initiatives to slow and limit the warning are needed.

Thank you.

Senator **Durenberger**. Thank you all.

I picked up the January issue of "Discovery," and there is an article in there and a picture of a distinguished looking gentleman lighting his pipe which I no longer do. I haven't done that for 11½ months. Under it, it says, "Koomanoff says those who link global warming to CO_2 build-up are blowing smoke." I think Koomanoff has some position and responsibility in this Administration. That seems to be his view.

How do the rest of you view the preparation being made for us currently at the national Government level for these problems? Are we preparing for them? Do we believe that people on this panel are blowing smoke? What is the perception of what our Government is doing to contribute to an international solution? Does anybody want to respond to that?

Dr. **MacDonald**. Mr. Chairman, I can start.

Mr. Koomanoff does have the carbon dioxide research program within the Department of Energy, and I am afraid his comment does reflect a prevailing attitude within Government at this time. There is first-class research conducted at NOAA and through the National Science Foundation's support of institutions such as the National Center on Atmospheric Research.

The work has largely centered on modeling, and I believe that this has been proper in the early stages. But as we get to know more about the complexities of the issue, there is going to, in my view, have to be a greater emphasis on, let's say, understanding the detailed chemistry within the atmosphere. This means making many measurements, using satellite observations, and having much more of an integrated program than we have today.

Research on the ecological aspects is fragmentary; very little is put together in any sort of coherent way. And yet I feel it is critically important to make judgments as to how our life-sustaining agricultural and other plant systems will respond to climatic changes and changes in atmospheric chemistry.

And finally, I strongly support Dean Abrahamson's comments with respect to the need for policy research. Very little is underway, other than that, I think, that he himself has led, and I believe that these separate elements do not go toward making a total program.

Current policy formulation efforts are highly fragmented. In the international arena, the World Meteorological Organization and the U.N. Environmental Program have initiated steps, but I think only in a preliminary way. A far broader and greater effort, again, perhaps along the lines suggested by Senator Gore, is something that I think is very much needed.

Senator **DURENBERGER**. Dr. Manabe, I wanted to return to the major point of your testimony, which was that you suggest that people who really understand the scenario of soil moisture change need to be able to somehow picture it in their mind; and you put up a "mind picture," and we had to take you back to the microphone.

Is there a region in our country or in the world that today has the temperature and moisture characteristics that your model indicates will prevail in the center of North America, for example, the Red River Valley in Minnesota, early in the next century?

Is there some place where, today, we can get a feel for what you model as tomorrow, and will these so-called dust bowl conditions prevail in other areas of the world like Europe and the Soviet Union and are there possibilities of that where there are other breadbaskets like in the Upper Midwest?

Dr. **MANABE**. As I mentioned already, the dust bowl drought during 1930's is a very good analogy to the summer dryness which is obained from our mathematical model of climate. If you are asking me if there are any other places with a similar climate it is difficult to identify such a place. The drought induced by greenhouse gases differ from the situation encountered in a desert because it is a summer phenomenon. The results from the climate model suggest that soil surface become wetter in winter in response to the increases in greenhouse gases.

As you know, there exists a large year-to-year fluctuation in soil wetness. The magnitude of the summer reduction of soil moisture due to the doubling of atmospheric carbon dioxide is comparable. with the natural fluctation of soil moisture from year to year. So, if we increase the capacity of water reservioirs in order cope with the natural fluctuation of soil wetness and river-runoff, we go a long way toward preparing for the summer drought which may result from the future increases of greenhouse gases.

Senator **DURENBERGER**. I have to depart.

I understand it is not without the tradition of this committee to permit Senators to continue meetings.

Senator Gore, we wish you were on the committee because I know of your interest. We have a large number of questions which will require a response in order to make a complete record. We have let the testimony go much longer than the usual 5 or 10 minutes that we restrict it to. But by the same token, I know all of you felt limited in what you were able to present here today.

I will now turn the hearing over to our colleague from Tennessee, and as long as he is willing and you are willing, we can continue this hearing, at the end of which I would appreciate you formally adjourning it.

Senator **GORE**. Mr. Chairman, I appreciate your courtesy very much. Because it deviates from the policy of the committee, I will not constrain the committee by asking many questions. I will ask a couple of brief ones, however, mainly about political questions.

As I understand your testimony, if we make the political choice of waiting to learn more about what is going to happen, the consequence of that choice will be to limit our options for responding to the greenhouse effect and by increasing the impact the world will likely experience as a result of the greenhouse effect.

Are you all in agreement with that statement?

Dr. MacDonald. I certainly am. I think the question of time scale is critical. To introduce a new energy source takes at least 50 years to change our water resource management infrastructure, or any of the underlying structures of our society takes a matter of several decades, yet we are talking about possible changes in times of a few decades.

Senator Gore. Yes.

Dr. MacDonald. It is that mismatch of time scales that makes this such a critical issue now and, indeed, if we wait too long, then the changes will be upon us, and reaction will be of the sort to limit damage rather than to manage for benefit.

Senator Gore. Does anyone disagree with the statement, as made?

The second proposition: In order for our country or for other countries with different political systems to organize a response equal to the challenge, we need a greater degree of certainty that such a response is absolutely essential in order to avoid the dire consequences sketched out by scientists like those on this panel.

At a very minimum, at a bare-bones minimum, therefore, the meagerest responsible approach would be to greatly accelerate the scientific efforts to reduce the remaining areas of uncertainty and enable policymakers to present their respective publics with evidence to which no one could respond as Mr. Koomanoff has responded by saying, "Convince me. I'm not sure this is real."

Ninety-five or ninety nine percent of the scientific community that has looked at the evidence agrees with the point of view expressed by this panel and by Dr. Sagan earlier.

You also qualify your statements responsibly by saying that the extent of the impact is unknown; the time in which the impact will first be felt cannot be predicted with precision, because we don't know enough about the ocean systems' interaction with increased CO_2 or about the possible adjustments in the cloud system as temperatures increase or about the contribution of trace gases, et cetera.

The caveats and qualifications diminish political will out of proportion to the effect they should have, because the central message you are giving us, stripped of qualifications and caveats, is that we have a global environmental disaster of virtually unprecedented dimensions building fairly quickly to a point where human civilization will almost certainly experience very large impacts in the next century. That is what the scientific evidence points toward. Is that a fair summary of it?

Dr. MacDonald. Yes, sir, Senator. There will always be uncertainty. We will never be able to predict the future with 100 percent confidence. It comes to mind that I, in this room, was testifying when Senator Muskie said, in a moment of exasperation, "Give me a one-handed scientist," because "on the one hand" and "on the other hand", and you have heard that today.

But we feel that there are uncertainties; the uncertainties will be reduced, but the problems and the consequences are so large that action over and above just further research, I believe, is warranted. Whether it is calling attention to the problem or taking measures along the lines that we have all talked about, energy efficiency, shift of fuels, limiting of the use of freons, or banning the use of freons. This whole series of actions that, in my view, are not likely to cause great economic disruption are at the same time able to provide us with the means and the time to more adequately deal with this longer term issue.

Dr. MANABE. Can I comment on the issue you raised?

Senator GORE. Yes.

Dr. MANABE. As pointed out by Dr. MacDonald, we will always have some doubt about the prediction obtained by use of mathematical models because climate models will never become perfect. Progress in model improvement has been steady, but very slow. I anticipate progress in the future will also be steady and slow.

How can we improve our confidence in these models? What we need is a support for a long-term monitoring of the atmosphere and the climate-causing factors. If the actual climate change as determined by such monitoring agrees with the prediction by a model, our confidence in the model improves. In addition, it is necessary to continuously improve mathematical models of climate. This will requires sustained, long-term research effort and a very large computer resource.

In my opinion, what we need is not intensive support during a short period of time, but a very sustained long-term commitment for the improvement of climate models and the monitoring of climate.

Senator GORE. Yes, sir.

Dr. CICERONE. Senator Gore, I am very encouraged by the fact that there is so much awareness and understanding of the principles, the physical, chemical, biological principles on behalf of people like you, and I see that consciousness growing around the world. I think one of next steps that will make many people feel more urgency with this set of questions is that of the timing of the effects, the modeling work that people like Dr. Manabe, who I believe in the next several years will be saying much more about the timing of these effects.

Up until now, it has been more common to deal with this canonical view of a doubling of CO_2 whenever it occurs. Now, there is much more attention being focused on the year in which certain effects might ensue or begin. This target exercise of the type Dean Abrahamson described I think would be very useful for us to get on with.

As the timing of the effects becomes clearer, we can identify targets at which the change will be detectable and acceptable or unacceptable and begin to identify what kinds of research are necessary in that area and what kinds of adaptation and policy has to follow.

I think we must identify some of those target levels. I am a little worried about a 5 degree rise in temperature being written off as unavoidable, for me. It seems to me on the high side to say that it is acceptable or unavoidable. Without the target levels, we won't know, because we won't have performed the biological adaptation studies, nor taken a look at the shifting ecosystems, nor a look at the policy impact tradeoffs.

I would like to stop my monologue with a reminder that the uncertainty we are dealing with exists on the high side, as well.

Senator **Gore**. That is right.

Dr. **Cicerone**. I don't think we know the result of these impacts as well. They may be much longer.

Senator **Gore**. Particularly if the ocean release of CO_2 turn out is as speculated and is on the high side.

Dr. **Cicerone**. A relevant issue we have to deal with, which is not as difficult as the ones you have to deal with, is how to get scientists together from different disciplines to do this multidisciplinary work as opposed to interdisciplinary work.

We are getting a lot of encouragement from places like the National Science Foundation and NASA, I think a little less encouragement from places like the Department of Energy.

Senator **Gore**. Yes, Dr. Abrahamson.

Dr. **Abrahamson**. I would like to comment. I don't mean to imply that 5 degrees is acceptable. I think it would be terrible. My point is that you don't even have to assume the upper end of all present estimates to get 5 degrees. Five degrees is a very plausible number. I think we are going to have to work hard to avoid an even greater warning. On your remarks specifically, Senator, three point: one is that working to get an international consensus of the scientific and technical community is very important. Things like the Villach meeting, do a lot to advance the understanding of the issue. There have been suggestions that a lack of getting this consensus before the United States takes vigorous policy action and may actually be detrimental. I don't know that this is true. I have often heard that when we moved rather quickly to ban the aerosol can use of fluorochlorocarbons part of the reason for the European delay was that the international scientific community was not sufficiently involved. I think that nongovernmental efforts to achieve a broader understanding on the scientific basis can do a lot. The second point is that the United States plays a big part in this problem, first of all, in its creation of the greenhouse gases, and second, in the means available to limit such releases. I certainly hope that no one is suggesting that we have to get an international consensus before we start to put our house in order. The third issue has to do with the matter of winners and losers. Some commentors very glibly say that some countries will be winners and some countries losers. The implication being, I gather, that some countries will want to encourage global warning rather than discourage it. I think that with a little work, one could make a pretty convincing case that there are probably no winners as the stress associated with responding to the temperature change will sop up so much capital and put so much stress into the system that it will be disruptive even if it could be shown that at equilibrium it may have been good. Second, the "winners and losers" argument also ignores the international political responses.

Senator GORE. I was encouraged by some favorable comments about my suggestion for an international scientific year focused on this problem, and I intend to pursue that.

With respect to your earlier comments and the interchange just now about whether or not 5 percent is inevitable and/or acceptable, I think the distinction between acceptable and inevitable is important. I take it that you don't disagree with that.

The underlying point which leads you to speculate this, Dr. Abrahamson, is that we have, in effect, already lost the option of having zero effect——

Dr. ABRAHAMSON. Yes.

Senator GORE [continuing]. Because of past practices and the past introduction of massive amounts of CO_2 into the atmosphere and other gases.

We have already programmed in a greenhouse effect of some magnitude. Does anybody disagree with that?

[No response.]

Senator GORE. Nobody disagrees with that. The question before us now, really, is twofold: First how do we get better, more accurate, and reliable information about exactly what is likely to take place when and where, since effects will be different depending upon the location? How do we get that information fairly quickly?

Second, at what point do policymakers decide that the information is of sufficient reliability on which to base intelligent decisions that have the potential for mitigating the impact?

The path of least resistance is, on both of those questions, to say, first of all, "Well, let's just wait and see," and second, "It turns out that it is too late to do anything. We will just adapt to it."

The reasons why those two strategies are not acceptable are that we can't just wait and see, because we have already programmed in some impact and, the longer we wait, the greater that impact will be.

If we have a clear understanding of how large the impact is likely to be, we would probably judge a policy of mere adaptation to be madness, even in light of the rather large changes necessary to mitigate the impact of the greenhouse effect.

You said, Dr. MacDonald, or I forget which witness said that deforestation may be equal to the extra introduction of CO_2 as a cause of this phenomenon? Am I remembering accurately?

Dr. MACDONALD. Yes. The biosphere, that is, the forest world, stores a great deal of carbon, as do the soils. And the deforestation currently underway, largely in tropical regions, could be increasing, in a very significant way, the overall CO_2 burden.

The fraction of the CO_2 increase that is due to industrial gases and that due to deforestation——

Senator GORE. Due to the deforestation?

Dr. MACDONALD. Yes, is not known.

Senator GORE. You sense is that it may be of roughly equal proportions?

Dr. MACDONALD. May be; it could be as large as the current increase. I think it is more likely that it is somewhat less.

Senator GORE. Less. I know that no firm scientific data is really available on this particular question, but I am interested from the other three panelists.

What is your gut feeling of how you rank the importance of decreased absorption by the world's forest and increased production of CO_2 and trace gases as causal factors here? Does anybody want to venture a guess?

Dr. **Cicerone**. I think the weight of the evidence is on the increase side of CO_2 and trace gases. It is unfortunate that some of the tools that would be available to settle that question either are no longer valuable, such as in the case of Carbon-14 studies, where the massive bomb testing in the atmosphere in the late 1950's and early sixties has rendered Carbon-14 work on methane less valuable than it would have been if the bomb testing had never occurred.

Second, we simply don't know how to measure the world's standing biomass to the accuracy required to know the difference between 99 and 100 units in a 5-year period. We don't have the satellite technology developed well enough yet to measure the changes in the biosphere fast enough.

So I think the weight of the evidence, then, is on the increasing side of the gases.

Senator **Gore**. Dr. Abrahamson?

Dr. **Abrahamson**. I called a number of my ecologist friends last week and asked them this question. The response I got was that the releases from deforestation now are probably not less than one gigatons per year, probably not more than four gigatons, and the fossil fuel emissions are in the neighborhood of five gigatons per year.

Dr. **Cicerone**. Right.

Senator **Gore**. I see. It is not negligible by anybody's calculations.

Dr. **MacDonald**. Certainly not.

Senator **Gore**. The reason I focus on that particular aspect of the issue is that as a politician looking at this problem in an overview, it is somewhat easier for me to imagine a global response to deforestation in the short term, although that would be quite difficult, than it is to imagine a decrease of fossil fuels in the short term.

If deforestation contributes anywhere from 20 percent to 45 percent of the problem, and it is feasible to begin addressing that in the short term, perhaps as a first order of political response we could begin imagining a global strategy to combat deforestation.

Again, as several witnesses indicated, there are other very good reasons for doing that, apart and aside from the greenhouse effect. However, in order to convince the world publics that this problem deserves that kind of response and attention, we need better information, and we need it quickly.

I personally am prepared to be convinced that the current state of information warrants an effort of that kind right now.

As a politician, I look at what is probably feasible, and I don't think that our Government, much less others, are yet prepared to undertake such a massive effort on the basis of the evidence we now have. I think that we should begin now, but I don't believe a consensus has yet been established in the political community that will match the consensus that has been impressively growing in the scientific community.

Dr. **MacDonald**. Senator Gore, I would like to use this opportunity to once again emphasize the connection. In connection with acid rain in Europe and in parts of this country, you have had associated with air pollution and generally with what is called acid rain destruction of forests. As those forests die, carbon is added to the atmosphere, and you have another clear illustration of how these systems are linked and that you must consider the impact of one action on others.

I think that the acid rain problem and the climate change problem are totally linked through atmospheric chemistry.

Senator GORE. Four years ago, I looked at that graph over there which traces the parts per million CO_2 in the atmosphere, and that particular version of the graph actually connects the peaks of the annual cycle. I was struck, as a member of the energy committee in the other body, that if you overlay a graph of world consumption of fossil fuels on that particular graph, the dips in 1969, 1970, 1975 1976 correspond almost exactly to the dips in this graph. I asked witnesses about it at that time, and they speculated that although that was an interesting correlation, it might be produced by a statistical artifact of some sort or another.

I am wondering if there has been any statistical work since then that sheds light on that particular correlation? If the answer is no, just say no.

Dr. CICERONE. I don't know the details of those years in my head, but I do know that there has been enough of a CO_2 record now to see the influences in energy usage upturns and energy usage downturns year by year, one time, at least. There has also been some dramatic connections with el Nino effects, with ocean surface temperatures, the effects of those and other surface circulations can be seen on CO_2 concentrations in the atmosphere.

Senator GORE. Presumably, something like el Niño would be sensitive to the measuring points, wouldn't it?

Dr. CICERONE. It is not everywhere, that is right.

Senator GORE. Wouldn't that balance out on a global basis if you just had a shift in the patterns of the ocean warmth?

Dr. CICERONE. There is a large regional response, not global, that is right. There is also the beginnings of evidence that the annual cycles in the CO_2 concentration that you referred to may be providing evidence about the amount of biomass change, that is, the respiration, the drawdown of CO_2 from the atmosphere being linked to the amount of living photosynthesizing material.

Senator GORE. Of course.

Dr. CICERONE. But the evidence in the record now is becoming clearer and clearer. It is not quite true yet that we can tell the changes in the world's biomass. But there is evidence now that the amplitudes of the CO_2 cycle are increasing a little bit.

Senator GORE. I hesitate to raise this question, but I will, because every once in awhile, somebody raises the question of other factors not often mentioned like termites. Have you dealt with that question? If so, dispel that, if you would.

Dr. CICERONE. Well, the termite work has been done, a large part of it, in our laboratory in Boulder and in the field in Africa and South America by our group, not me directly, but people working with me. It arose mostly in connection with atmospheric methane, where it is absolutely clear that microbes living inside termite ducts do produce prodigious amounts of methane.

Senator **Gore**. When you look at the magnitude involved, it really isn't very, very large.

Dr. **Cicerone**. And carbon dioxide. But if you are thinking about global change——

Senator **Gore**. It has been constant?

Dr. **Cicerone** [continuing]. That is the question. The ecologists are pondering whether the termite populations increase dramatically after an episode of forest clearing or whether the termites are not quite so opportunistic, and I don't believe that question is settled.

Senator **Gore**. It could, instead of just being a constant over the last several million years, be a kind of a flywheel effect that increases CO_2 levels in the wake of deforestation episodes?

Dr. **Cicerone**. Well, increased populations of termites would recycle things faster. You might get CO_2 exiting faster than if you didn't have termites.

Senator **Gore**. Given the magnitude of the gases involved, it would be statistically insignificant for measuring?

Dr. **Cicerone**. Yes. We don't normally think of these things. But the termites are on the lower end of carbon cycling and cycle an enormous amount of carbon. But they are part of nature that has been there for a long time.

Senator **Gore**. Fluorochlorocarbons, while small in total volume, are very powerful in their ability to absorb infrared rays; correct?

Dr. **Cicerone**. Yes.

Senator **Gore**. Based upon your calculations, CFC's may account for approximately one-third of the greenhouse effect at the present time; is that too large a figure?

Dr. **Cicerone**. I think that it is growing. I am not sure it is a third yet, but it is approaching that figure.

Senator **Gore**. In that order of magnitude?

Dr. **Cicerone**. Right.

Senator **Gore**. You mentioned earlier, or one of the witnesses mentioned earlier the lack of response in Europe as compared to the United States action in banning CFC's. If we wanted to come up with an effective measure now, we could push for bans elsewhere on CFC's in the short term, and that would have an effect that would not be negligible.

Does anybody disagree with that?

Dr. **Cicerone**. No, but care has to be taken to recognize the changing usage pattern. In the United States when the action was taken by, I think, three agencies together in the late seventies, there was leverage over what was judged to be less essential usages, such as aerosol spray propellants. The changing usage now is characterized by you might say, more essential usages in many countries, although in many other countries of the world, the aerosol usage, which I think is correctly judged to be less potential, still proliferates.

So there is some leverage there, yes.

Senator **Gore**. Yes.

Chairman Durenberger indicated that he would have other questions in writing. I know that other members of the committee will, as well, and I appreciate his courtesy in letting me finish this up and ask questions. On behalf of him and the committee, if I may presume to do so, I would like very much to thank all of you for your testimony here today and your responses to the questions. We will stand adjourned.

[Whereupon, at 1:05 p.m., the subcommittee was recessed, subject to the call of the Chair.]

[Statements submitted for the record follow:]

STATEMENT OF THE HONORABLE
ALBERT GORE, JR.
DECEMBER 10. 1985

THANK YOU, MR. CHAIRMAN.

I AM PLEASED TO HAVE THE OPPORTUNITY TO TESTIFY BEFORE THE SUBCOMMITTEE ON TOXIC SUBSTANCES AND ENVIRONMENTAL OVERSIGHT ON THE GREENHOUSE EFFECT. I WANT TO CONGRATULATE YOU, MR. CHAIRMAN, FOR YOUR LEADERSHIP IN CALLING A HEARING ON THIS IMPORTANT ISSUE, WHICH HAS BEEN LARGELY IGNORED BY MANY POLICY MAKERS.

MODERN MAN HAS ACQUIRED THE TECHNOLOGY TO CATASTROPHICALLY MODIFY THE FAGILE ATMOSPHERE OF OUR PLANET. SIMPLY BURNING FOSSIL FUELS FOR WARMTH COULD HAVE THE INSIDIOUS LONG-TERM EFFECT OF WARMING THE GLOBE. THE BUILDUP OF CARBON DIOXIDE, AS WELL AS OTHER TRACE GASES, TRAPS RADIATION, CAUSING THE ATMOSPHERE TO HEAT UP--A PHENOMENON CALLED THE GREENHOUSE EFFECT. IF TODAY'S WORST CASE SCENARIOS BECOME TOMORROW'S FACTS, WE WILL THEN HAVE ONLY A FEW DECADES IN WHICH TO AMELIORATE THE IMPACT--WHICH COULD RANGE FROM DROUGHT IN THE MIDWEST TO FLOODS ON THE COAST.

FOR THOSE UNFAMILIAR WITH THE GREENHOUSE EFFECT, IT MAY SOUND MORE LIKE A PLOT FOR A BAD SCIENCE FICTION STORY THAN A SERIOUS ENVIRONMENTAL ISSUE DESERVING PUBLIC POLICY REVIEW OF THE HIGHEST ORDER. BUT, GIVEN ITS SERIOUS AND POTENTIALLY DRASTIC IMPACTS, FEDERAL RESEARCH AND STUDY EFFORTS MUST PLACE THE GREATEST PRIORITIES ON SOLVING THE MYSTERIES SURROUNDING THE GREENHOUSE EFFECT. OTHERWISE, FUTURE GENERATIONS MAY EXPERIENCE A SCIENCE FICTION STORY THAT COMES TRUE.

MY INTEREST IN THE GREENHOUSE EFFECT GOES BACK SEVERAL YEARS AND INCLUDES THREE CONGRESSIONAL HEARINGS WHICH I CHAIRED. DURING THE FIRST HEARING IN 1981, A NUMBER OF PROMINENT SCIENTISTS, INCLUDING ROGER REVELLE OF THE UNIVERSITY OF CALIFORNIA TESTIFIED THAT THE GREEHNOUSE EFFECT WAS NOT A THEORETICAL ENTITY BUT VERY REAL. THIS MARKED THE FIRST TIME THAT THE SCIENTIFIC COMMUNITY HAD REACHED A CONSENSUS ON THIS POINT.

THE EVIDENCE TO SUBSTANTIATE THIS CONCLUSION WAS NOT LONG IN COMING. IN 1982, JAMES HANSEN OF NASA AND GEORGE KUKLA, WITH COLUMBIA UNIVERSITY, TESTIFIED THAT THE RISE IN CARBON DIOXIDE LEVELS COULD BE CORRELATED VERY CLOSELY WITH A RISE IN THE EARTH'S MEAN TEMPERATURE, A SHRINKING OF THE POLAR ICECAPS, AND THE RESULTING RISE IN THE EARTH'S MEAN SEA LEVEL. AT THAT TIME THE WASHINGTON POST, IN AN EDITORIAL, STATED THAT THE GREENHOUSE

EFFECT WAS NO LONGER JUST SOMETHING FOR THE "SANDALS AND GRANOLA" CROWD. IT WAS IN THE MAINSTREAM OF SCIENTIFIC THOUGHT.

THE MOST COMPREHENSIVE EVALUATIONS OF THE GREENHOUSE EFFECT WERE PRESENTED AT THE THIRD HEARING IN 1984. ONE WAS AN EPA REPORT THAT PREDICTED THAT THERE WOULD BE A GLOBAL TEMPERATURE INCREASE OF 3.6 DEGREES FAHRENHEIT BY THE YEAR 2040, AND A RISE OF AS MUCH AS 9 DEGREES FAHRENHEIT BY THE YEAR 2100. THIS WOULD RESULT IN SEA LEVEL INCREASES RANGING FROM 4.5 TO 7 FEET BY THE END OF THE NEXT CENTURY.

A REPORT FROM THE NATIONAL ACADEMY OF SCIENCES WAS MORE CONSERVATIVE IN ITS PROJECTIONS. THE NAS PREDICTED A 2 TO 8 DEGREE FAHRENHEIT RISE IN TEMPERATURE ALONG WITH A "MODEST" 2.5 FOOT RISE IN THE SEA LEVELS BY THE YEAR 2100. THE MAJOR DIFFERENCES BETWEEN THE TWO STUDIES WAS THAT EPA INCLUDED THE IMPACT OF GREENHOUSE GASES, SUCH AS FREON AND METHANE, AS WELL AS CARBON DIOXIDE. THE ACADEMY PROJECTIONS, HOWEVER, WERE BASED SOLELY ON INCREASED CARBON DIOXIDE CONCENTRATIONS.

SINCE THE RELEASE OF THOSE TWO STUDIES, PROBABLY THE MOST SIGNIFICANT EVENT TO OCCUR WAS A CONFERENCE ON THE GREENHOUSE EFFECT THAT BROUGHT SCIENTISTS FROM 29 COUNTRIES TO VILLOCK (PRONOUNCED VEE-LOCK) AUSTRIA THIS PAST OCTOBER. THESE SCIENTISTS CONCLUDED THAT "...GREENHOUSE GASES ARE LIKELY TO BE

THE MOST IMPORTANT CAUSE OF CLIMATE CHANGE OVER THE NEXT CENTURY." THIS CONCLUSION WAS THE BASIS FOR A RECOMMENDATION THAT "GOVERNMENTS...SHOULD TAKE INTO ACCOUNT THE RESULTS OF THIS ASSESSMENT IN THEIR POLICIES ON SOCIAL AND ECONOMIC DEVELOPMENT, ENVIRONMENTAL PROGRAMS, AND CONTROL OF EMISSIONS OF RADIATIVELY ACTIVE GASES."

IN THE PAST FEW YEARS, THE SCIENTIFIC COMMUNITY HAS MOVED FROM UNCERTAINTY ABOUT THE GREENHOUSE EFFECT TO SPECIFIC RECOMMENDATIONS ON HOW TO ADDRESS THE ISSUE. HOWEVER, THERE ARE STILL DISAGREEMENTS AS TO THE SEVERITY OF THE EFFECT AND THE AMOUNT OF TIME THAT WE MAY HAVE IN ORDER TO AMELIORATE THE IMPACT.

IN ORDER TO DECREASE THE SCIENTIFIC UNCERTAINTIES AND TO PROVIDE MORE INFORMATION FOR POLICY MAKERS, I AM PROPOSING LEGISLATION THAT WOULD EXPAND AND FOCUS SCIENTIFIC EFFORTS ON THE GREENHOUSE EFFECT AND ITS CONSEQUENCES FOR SOCIETY. THE LEGISLATION WOULD CALL FOR THE ESTABLISHMENT OF AN INTERNATIONAL YEAR OF SCIENTIFIC STUDY OF THE GREENHOUSE EFFECT, AND WOULD REQUEST THAT THE PRESIDENT TAKE STEPS TO BEGIN THIS WORLDWIDE COOPERATIVE INVESTIGATION. THIS WOULD BE JUST THE BEGINNING, MANY OF THE STUDIES WOULD NEED TO CONTINUE FOR YEARS.

THE LEGISLATION WOULD (1) COORDINATE AND PROMOTE DOMESTIC AND INTERNATIONAL RESEARCH EFFORTS ON BOTH THE SCIENTIFIC AND POLICY ASPECTS OF THIS PROBLEM; (2) IDENTIFY STRATEGIES TO REDUCE THE INCREASE OF CARBON DIOXIDE AND GREENHOUSE GASES; (3) STUDY WAYS TO MINIMIZE THE IMPACT OF THE GREENHOUSE EFFECT; AND (4) ESTABLISH LONG-TERM RESEARCH PLANS.

THE CONCEPT OF AN INTERNATIONAL YEAR OF STUDY HAS BEEN USED SUCCESSFULLY IN THE PAST. IN FACT, THE BEST AND MOST COMPLETE COLLECTION OF DATA BASED ON ATMOSPHERIC CONCENTRATIONS OF CARBON DIOXIDE BEGAN IN 1957 AS A RESULT OF THE INTERNATIONAL GEOPHYSICAL YEAR. AT THAT TIME A SAMPLING STATION WAS ESTABLISHED ON MONA LOA, HAWAII. TODAY SCIENTISTS ARE STILL COLLECTING DATA FROM THAT STATION.

NOW MORE THAN EVER BEFORE, WE STAND AT THE DOOR OF OPPORTUNITY, WONDERING WHETHER THE DOOR WILL CLOSE BEFORE WE ACT TO CONTROL THE GREENHOUSE EFFECT, OR WHETHER THAT DOOR WILL REMAIN OPEN LONG ENOUGH FOR US TO ESTABLISH A WORKABLE CORRECTIVE POLICY.

THANK YOU MR. CHAIRMAN. I WOULD BE HAPPY TO ANSWER ANY QUESTIONS.

Testimony of	Dr. Ralph J. Cicerone, Director Atmospheric Chemistry Division National Center for Atmospheric Research Boulder, Colorado 80307
Presented to	United States Senate Committee on Environment and Public Works Subcommittee on Toxic Substances and Environmental Oversight

December 10, 1985

In the time available this morning I will describe the characteristics of greenhouse gases and their leverage on the Earth's climate, as well as provide up-to-date information on the striking increases in the concentrations of these gases in the global atmosphere. I will also summarize what is known about the causes of these global increases and the closely related issue of how well we can predict corresponding future changes.

If there were an accountant who was assigned to keep books on the energy budget of the Earth, he could do half of the job to rather good accuracy each year by logging in the visible sunlight received at the Earth's surface as the total income. On the outflow side of the ledger, he could simply record the total amount of infrared energy leaving the atmosphere. At this point, the audit would be done and the books should be balanced; inflow should be close to equal to outflow for an Earth whose annual average temperature is constant. A more detailed examination of the outgoing infrared energy that escapes Earth's atmosphere to outer space would show that a substantial fraction is carried by a small band of infrared wavelengths (8 μm to 12 μm). This is true for two reasons. First, the Earth's surface radiates well at these wavelengths, and second, the atmosphere is relatively transparent from eight to twelve μm. Because of this transparency, we refer to this wavelength band as the *Atmospheric Window*. We know that this window should exist from the fundamental spectroscopic properties of the gases that comprise our atmosphere. Infrared observations of the Earth from space do indeed confirm the presence of this window band of wavelengths.

How might an individual attempt to alter Earth's climate? We could imagine ways to darken the Sun itself or to reflect sunlight back to space by wrapping the Earth and its atmosphere inside shiny tin foil. Both ideas are hare-brained, of course. What about heating the Earth by burning more fuel and chopping and burning trees? In this case the idea is straightforward but the numbers don't add up. The total rate of human energy usage today is less than one ten-thousandth of the rate at which the Sun's visible energy arrives. It is easy to see that someone who is bent on changing the climate needs some leverage; the task is formidable.

Greenhouse gases can provide enormous leverage to alter Earth's energy budget by decreasing the infrared transparency of the atmosphere, or dirtying the atmospheric window. What properties constitute effective greenhouse gases? Their molecular structures should be such that they absorb infrared radiation strongly at wavelengths between 7 and 13 μm or thereabouts and they should be able to stay airborne without decomposing for long periods of time, say a year or more. Long survival times (or atmospheric residence times) allow relatively small sources of chemicals to be adequate and they permit global or near-global spreading of the chemical in the air. A wholly natural chemical, water vapor, is a very important present-day greenhouse gas even though its residence time near the surface is only a few days: prodigious amounts of H_2O are cycled through the atmosphere.

Our present concern is that the concentrations of many very effective greenhouse gases are increasing in the global atmosphere. These include carbon dioxide, a dozen or so synthetic halocarbon chemicals, methane, nitrous oxide and ozone in the lower atmosphere (troposphere). Ozone changes in the upper atmosphere (stratosphere) can also affect temperatures at the surface. This committee is well aware of the prospects of climate effects due to CO_2 increases; I will focus on the other trace gases mentioned earlier. The term *trace gas* connotes being present in minute, or trace, amounts, parts per million or less.

Of all the gaseous chemicals relevant today, the halocarbons stand out in several ways. Their concentrations in the atmosphere are the smallest, their annual percentage rates of increase are the largest and their sources are the simplest to understand; they are manmade. The chief greenhouse gases in this group are fluorocarbon-12 (dichlorodifluoromethane, CCl_2F_2), fluorocarbon-11 (trichlorofluoromethane, CCl_3F), trichloroethane ($C_2H_3Cl_3$) and fluorocarbon-113 (trichlorotrifluoroethane, $C_2Cl_3F_3$) although other such chemicals require attention (see Appendix 1). The atmospheric residence times of these chemicals are about 120, 70, 10 and 200 years, respectively. The concentrations of CCl_2F_2, CCl_3F and $C_2H_3Cl_3$ are about 400, 240 and 125 parts per trillion, respectively. CCl_2F_2 and CCl_3F are increasing by roughly 5% per year and $C_2H_3Cl_3$ by 8% annually. Through the 1970's the percentage rates of increase were larger. $C_2Cl_3F_3$ is less concentrated but is increasing faster. Ten years ago CCl_3F and CCl_2F_2 were used mostly as aerosol propellants and as refrigerants and the U.S. accounted for about half the total world production and usage. Now the aerosol application represents a smaller proportion, especially in the U.S., and the U.S. production and usage is a smaller part of the world's. Fairly detailed information is available on how each chemical is used as a refrigerant, aerosol propellant, foam-blowing agent, degreasing agent, or as a cleaner or solvent, at least for the U.S. market and for other advanced nations. Generally speaking, we expect continued future growth rates of 2-5% per year or more in the emissions of these chemicals into the 21st century.

In the case of nitrous oxide (laughing gas, N_2O) we are unsure as to why it is increasing but measurements from all over the world have established that it is. The 1985 concentration of N_2O is about 300 parts per billion; this adds up to 2400 million metric tons of N_2O in the global atmosphere, most of which is natural. We now believe that the atmospheric residence time of N_2O molecules is 125 years or so. Thus the total annual sources should add 20 million tons to the air and an equal tonnage would be decomposed in the (upper) atmosphere if we were looking at a steady system. Instead, we know that N_2O concentrations are increasing at about 0.2% per year. This rate might sound small to you but it actually signals a large global perturbation and one that has been sustained and growing since the early 1960's at least. It takes 5,000,000 extra tons of N_2O annually to cause this increase; whatever the identity of this extra source it is now about 25% as big as the total of all natural sources.

Two possible N_2O sources seem likely. One is the inadvertent loss of artificial nitrogen fertilizer from fertilized fields and from subsequent nitrogen cycling. Some N_2O escapes into the air from soils and water bodies during two processes of nitrogen cycling: nitrification and denitrification. The second candidate as an N_2O source is the combustion of nitrogen-rich fuels; the higher the nitrogen content of various fuels, the more the N_2O production, it appears. It should be noted that world demand for N fertilizers keeps growing. In 1950 only about 3,000,000 tons were produced. In recent years the annual total was over 50,000,000 tons. Similarly, as you know, fuel combustion increases at 2-4% per year although the mix of fuels varies and the rates track the general economy.

Atmospheric methane (CH_4) is increasing at more than 1% annually now all over the world. In the northern hemisphere there are about 1.65 parts per million of this gas; in the southern hemisphere there is about 6% less, probably because the dominant sources are in the north and the tropics. By going through arguments involving the total amount (5,000 million tons) in the global atmosphere, the residence time (10 years) and the rate of increase one can deduce that the present annual source would have to be 500 million tons just to hold the methane concentration constant and an extra 50 or 60 million tons is needed to cause the measured annual increase. Some dramatic recent findings show that methane concentrations have increased by 100% or more since the Industrial Revolution and since 1950 the increase has been 30-40%.

I can present plausible views of why methane is increasing, views that do not violate any of the constraints provided by available scientific data. These involve the increased populations of ruminant animals, increased land areas under rice agriculture and multiple cropping of rice from increased irrigation, the increased mining of coal and natural gas and increased burning of tropical biomass. There is controversy over which of these growing sources is most responsible for the methane buildup or whether some other unidentified source is operating.

It is very useful, both scientifically and for policy issues, to distinguish between methane that has arisen from the decomposition of organic material that was alive recently (e.g., from swamps, marshes, rice paddies, ruminant guts, biomass burning, etc.) and methane from ancient organic material (e.g., natural gas pockets, burning of petroleum, etc.). An obvious tool to use is the Carbon-14 (radioisotope) method of carbon dating. Unfortunately much of the potential utility of C-14 studies have been vitiated by the artificial C-14 that was injected into the atmosphere by the bomb testing of the 1950's and 60's (less since the Test Ban Treaty). Various methods of research are being applied to the question of methane sources: field measurements of source activities, observing and modeling methane patterns and changes and studies with the Carbon-13 (stable) isotope.

There is another live and logical possibility--that the explanation lies wholly or in part in a decreasing ability of the atmosphere to decompose (oxidize) the methane that enters the atmosphere. There is one chemical in the atmosphere that apparently accounts for 90% of the atmosphere's ability to decompose methane. It is the gaseous hydroxyl (OH) radical, a fragment of the water molecule. This species owes its existence to chemical reactions in the atmosphere that are driven by ultraviolet radiation from the sun. The hydroxyl radical is the dominant sink (destruction process) for many other chemicals besides methane, for example, carbon monoxide, a variety of hydrocarbons and some sulfur compounds. Anything that can suppress OH concentrations would act to increase atmospheric methane concentrations. Several scientists have pointed to a specific mechanism: if carbon monoxide concentrations are increasing (there is some evidence of this) then OH could be decreasing and methane could increase without increasing methane sources. Similarly, if methane sources increase so that methane concentrations increase, this would also suppress OH levels throughout much of the atmosphere which would then allow carbon monoxide to increase. This nonlinear atmospheric photochemical feedback system was identified nine or ten years ago; at the time no one knew that methane was increasing and we did not dream that it could increase as fast as it is now.

Atmospheric ozone changes are also underway. In the troposphere, ozone is increasing in the northern hemisphere but too few measurements make this increase hard to quantify. The atmospheric chemistry that creates ozone involves hydrocarbon gases and nitrogen oxide gases like nitric oxide and nitrogen dioxide; reactions involving these species brew ozone and photochemical smog in industrialized cities. On a hemispheric or global scale, we are less sure about the quantities of all the ozone-precursor species and of ozone itself and of the rates of production of ozone so we cannot be very clear about predictions of future ozone changes. Also, global ozone changes are probably underway in the stratosphere because of manmade chlorofluorocabon gases and the same methane and nitrous oxide increases I mentioned earlier. We think that ozone is decreasing in the upper stratosphere and increasing in the lower stratosphere with a net warming greenhouse effect.

In the appended scientific papers, we present estimates of the climatic effects of the trace gases that I have mentioned here plus some others. We have also identified a number of other atmospheric chemicals that will not be effective greenhouse gases and a few chemicals that are potentially important but for which we lack the information necessary for quantitative estimates. The other trace gases are already contributing over half as much radiative forcing as the increased CO_2 to date. Based on our projections of future trace-gas increases the gases besides CO_2 can contribute as much as CO_2 to future warmings or even twice as much by the middle of the next century.

The timing of all the projected climate effects remains unclear, mostly because no one can be sure of the natural lag time in the response of the Earth's physical and biological climate-control system. Heat transfer from oceanic surface waters to deeper waters could pace the rate at which Earth's climate equilibrates to a new energy budget. The globally averaged temperature increases that we have calculated due to continued increases of CO_2 and these other gases are measures of the final equilibrated response to the radiative forcings of these gases and to the increased water vapor assumed to be airborne at the higher temperatures.

Predictions of globally averaged temperature changes are not numbers that grab people; indeed they are not the most meaningful indicators of climate change for most humans. Instead we need to know the details of regional and seasonal changes, for example, how many consecutive frost-free nights will there be in the U.S. or Soviet grain belt as climate changes? Nonetheless, the crude indicators such as the amount of change in radiative forcing and change in global average temperatures provide a planetary perspective on the size of the impacts to be expected.

Humans are pushing CO_2 concentrations higher than they have been before in recorded history and higher than they seem to have been during recent interglacial warmings of the past several tens of thousands of years. Whatever the effects of the contemporary CO_2 increase they should be larger than those due to any known sustained change in the Sun's output of the last 100,000 years or more. Now we know that other trace gases are adding to the perturbation.

On the bright side, we have made great progress toward understanding and predicting climate change even though we are still far from the goal and no perfect prediction is even possible. It is truly amazing to see how the pieces of the science of the environment have developed in the last fifteen years. We now have the wherewithal to convert these pieces, these individual disciplines into useful tools. Atmospheric chemistry, for example, is poised for major advances in understanding, many of which are feasible due to the work of our colleagues in physics, chemistry and biology. Even more dramatically, we now have useful guiding concepts of how the entire coupied climate system works and how the Earth's biota, both marine and terrestrial, are involved with the physics of the atmosphere and the oceans and with surface hydrology.

So there is a race underway. It pits a nascent but capable scientific community against the unknowns of the global changes that we are discovering. One can see easily that speed and stamina are involved in this contest on both sides. Increases in population, energy usage and chemical technology will probably be sustained if not accelerated. Efforts to penetrate the situation scientifically can keep pace if we hustle. Certainly there are commensurate, if not larger, public-policy challenges-- some of which must await better scientific data.

STATEMENT OF
SYUKURO MANABE
GEOPHYSICAL FLUID DYNAMICS LABORATORY
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

BEFORE THE

SUBCOMMITTEE ON TOXIC SUBSTANCES AND ENVIRONMENTAL OVERSIGHT
ENVIRONMENTAL AND PUBLIC WORKS COMMITTEE
UNITED STATES SENATE

December 10, 1985

Mr. Chairman and members of the Subcommittee, I appreciate the opportunity to appear before you today on behalf of the Department of Commerce to comment on Climate Warming due to Greenhouse Gases.

It has been suggested that increases of atmospheric trace gases such as carbon dioxide (CO_2), chlorofluorocarbons (CFC), methane (CH_4), and nitrous oxide (N_2O) would warm the climate by trapping outgoing radiation from the atmosphere. These "greenhouse gases" are known to be steadily increasing with time. It is now generally accepted that the role of greenhouse gases other than CO_2 in changing climate is already as important as that of carbon dioxide itself. The expected climatic changes due to increases of greenhouse gases is the subject of this presentation.

One of the most important tools for the study of this problem is a global model of climate. Such a climate model consists of a system of mathematical equations that represent the laws of physics governing the behavior of the atmosphere and oceans. The atmospheric component of a climate model is essentially similar to the numerical weather prediction models which have been used successfully by the weather services of the United States and many other countries. Scientists have shown that state-of-the-art climate models can successfully reproduce the geographical and seasonal variations of climate. Encouraged by these successes in climate simulation, atmospheric scientists have used climate models for studies of a wide variety of problems; a major emphasis has been on understanding climatic changes due to increases of greenhouse gases in the atmosphere.

Recently, an international conference of experts was organized jointly by WMO,* UNEP* and ICSU* at Villach, Austria to assess the climatic effect of increased greenhouse gases and their possible associated impacts. I was one of the participants in this conference. The executive summary of the conference report concluded that, if the present trend continues, the combined concentrations of carbon dioxide and other trace gases in the atmosphere would be radiatively equivalent to a doubling of carbon dioxide from preindustrial levels possibly as early as the 2030's. Based upon the results from the most advanced climate models, the summary states that such an increase of greenhouse gases would raise the global mean surface air temperature between 1.5 - 4.5°C (2.7 - 8.1°F). The report cautioned, however, that values outside this range cannot be excluded because of imperfections in climate models, particularly with respect to ocean-atmosphere interaction and cloud-radiation processes. Due to the thermal inertia of oceans, the warming will be delayed by several decades. Nevertheless, it is probable that the global mean warming of 1.5 - 4.5°C indicated above will be reached during the second half of the next century if the present trends in the increase of greenhouse gases continue. The report noted that such a climate change would have far reaching impacts on human life and the planet's ecosystems.

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* WMO : World Meteorological Organization
ICSU: International Council of Scientific Union; and
UNEP: United Nations Educational Program

At the Geophysical Fluid Dynamics Laboratory of NOAA (GFDL) my colleagues and I have been working on developing advanced climate models for nearly 25 years. One of the main thrusts of my own work over that period has been the carbon dioxide climate warming problem.

According to climate models developed at the GFDL and other institutions, the expected warming induced by greenhouse gases will not be uniform geographically. For example, the increase of surface air temperature is expected to be particularly large in high latitudes during late autumn and winter. This will make winters less severe over Siberia and Canada. One of the consequences of the increased greenhouse gases will be a reduction of sea ice coverage over the high latitude oceans. In the tropics, the model-predicted increases of surface air temperature are usually smaller than the global mean increase. The latitudinal and seasonal variation of the surface air temperature change described above has been inferred from the response of climate models to an increase of atmospheric carbon dioxide. Essentially a similar response is expected to result from the increase of other greenhouse gases identified earlier.

It is expected that increases of greenhouse gases will also affect the wetness of the continental surface and the hydrologic cycle. Because of the penetration of warm, moisture-rich air into high latitudes, a doubling of atmospheric carbon dioxide or equivalent might increase the rate of river-runoff over Northern Canada and Siberia by 20 - 40%.

Our GFDL climate model also indicates that, in response to the increased greenhouse gases, summer drought will become more frequent over the mid-continental regions in middle latitudes. The model-produced summer drought over the Great Plains of North America is characterized by a reduction of soil moisture, less cloudiness and a marked increase of soil surface temperature. This situation resembles the extreme summer drought of 1930's. when the area-mean surface air temperature of the Northern Hemisphere was above the normal value.

Fig. 1 shows the predicted change in soil wetness obtained from our recent climate models developed at GFDL. It illustrates, for the June-July-August period, the percentage change of soil moisture induced by a doubling of atmospheric carbon dioxide. In view of the limitation of current climate models, the details of the geographical distribution shown here should not be taken literally. Nevertheless, this figure shows that soil moisture reduces substantially over the Great Plains of North America, Western Europe, Northern Canada, and Siberia. It was found that the predicted summer reduction of soil moisture over the Great Plans is caused by the earlier commencement of the spring to summer-reduction of soil moisture which results from the earlier terminations of the late winter snowmelt season and the spring rainy period.

The mid-continental summer drought described above results from the surface warming which increases with increasing latitudes. However, it does not critically depend upon the details of the pattern of the warming. Although the present result was obtained as an equilibrium response to a doubling of atmosphere carbon dioxide, it is expected that similar features will emerge in a transient response of the model to a gradual increase of greenhouse gases.

Major uncertainties remain in estimates of climate change due to increased greenhouse gases. For example, it is difficult to estimate with confidence the delay in climatic response due to the thermal inertia of oceans. This is because the oceanic part of climate models is at an early state of development. The model uncertainties are also due to our inability to model accurately the interaction between cloud cover and radiative transfer in the atmosphere. Currently, oceans and cloud cover are two of the subjects selected for intensive research in the World Climate Research Program.

After listening to my presentation, you may wonder whether the climate may have already changed due to past increases in the greenhouse gases. The Villach Conference Report noted that the global mean temperature has increased by about 0.3 - 0.7°C during the last 100 years. This is consistent with the expected warming due to carbon dioxide and other greenhouse gases. However, the report points out that this past warming cannot be proven to be caused by the increase of greenhouse gases. This is because of the lack of reliable information on the past variation of the factors that can cause climatic change.

To detect future changes of climate due to greenhouse gases, it is imperative that we monitor the basic variables describing climate, as well as the factors that can cause its change. These measurements will require a sustained and serious commitment on the part of this country. In addition, real progress will require increased levels of international scientific cooperation in monitoring and modeling of climate.

Mr. Chairman this completes my prepared statement. I would be glad to answer any questions you might have.

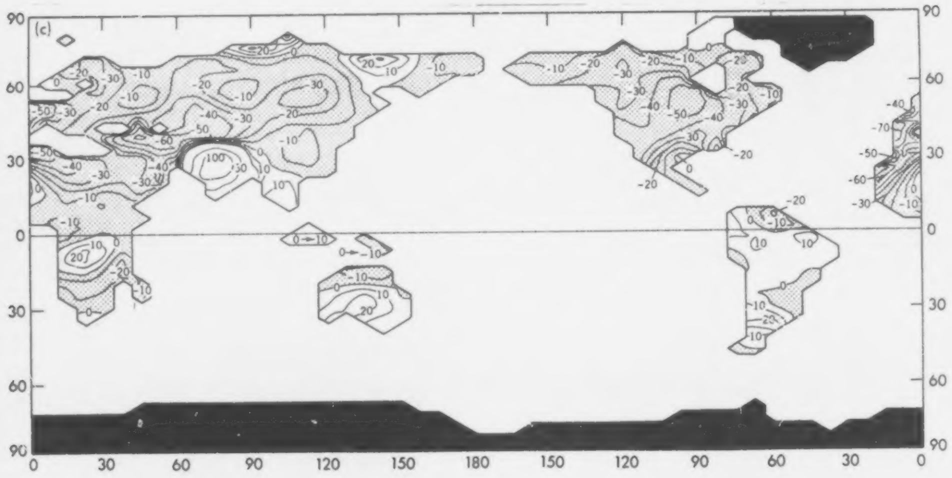
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Fig. 1. The geographical distribution of the percentage change of soil moisture in response to a doubling of CO_2 content for the June-July-August period. The results are obtained from a general circulation model of climate developed at the Geophysical Fluid Dynamics Laboratory of NOAA. Note that the statistical significance of the changes in the Southern Hemisphere and the low latitudes of the Northern Hemisphere are low.

GLOBAL CLIMATE CHANGE

Testimony by Gordon J. MacDonald*
Before the Subcommittee on Toxic Substances and
Environmental Oversight of the United States Senate
December 10, 1985

Mr. Chairman, Members of the Committee:

I very much appreciate the opportunity to discuss with you selected aspects of anticipated problems related to man-made climate change. My instructions from the committee for this morning are straightforward. I am to provide a general overview of:

- Role of the oceans in delaying climate warming, including positive or negative feedback effects.
- Possible impacts of hydrologic changes on global ecology and, specifically, North American agriculture.
- Plausible governmental, or broader social responses as first steps toward alleviating climate change.

I am to present this general overview in ten minutes or less saving time to discuss any other issues of particular interest. Undaunted by the clear impossibility of meeting your requirements, I will briefly outline the salient issues involving both the impact of

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Dr. Gordon J. MacDonald is Vice President and Chief Scientist of The MITRE Corporation, 1820 Dolley Madison Boulevard, McLean, VA 22102.

climate change on the oceans and biosphere, and their role in modulating climate change. My emphasis will be on those issues which might be influenced by legislative actions originating in this committee.

As my distinguished fellow panelist have made clear, the industrial infrastructure supporting the world's four billion people produces quantities of carbon dioxide and other trace gases large enough to change, in a significant way, the composition of the atmosphere. This change can effect the oceans and biosphere directly and indirectly. As the concentration of carbon dioxide increases in the atmosphere, so will the amount of carbon dioxide present in the surface layers of the oceans. Atmospheric and dissolved carbon dioxide are converted to solid carbohydrates by plants in photosynthesis. As carbon dioxide levels increase, the rate of photosynthesis quickens, provided sunlight and nutrients are abundant. Thus, the immediate direct response of the biosphere and oceans to heightened atmospheric carbon dioxide levels is to absorb some fraction of the added carbon dioxide: As a result, the increase in atmospheric carbon dioxide should be less than the amount of carbon dioxide produced by industrial activity. Atmospheric carbon dioxide levels have been accurately measured since 1958, and the amount added is known to a few percent. The measured increased atmospheric burden of carbon dioxide is only about 45% of the added carbon dioxide added by man. This fraction has remained more or less constant over the past 25 years. The remaining 55% of the added carbon dioxide is sequestered in the oceans and biosphere but the relative proportions are not known. Indeed, the biosphere may not be a net sink for carbon dioxide. Destruction of forests by clearing new land--particularly in the tropics--or through the action of acid deposition, returns some of the carbon stored in plants and soils to the atmosphere. Today, we do not know whether the biosphere is a net sink or source for carbon dioxide. Major uncertainties thus exist in our understanding of the direct response of the oceans and biosphere to increased atmospheric carbon dioxide levels.

The situation becomes more complex as we take into account the indirect effects of altering atmospheric composition. As the atmosphere warms so will the ocean waters in contact with the air. Warmer waters hold less carbon dioxide than colder waters; water just above freezing can absorb twice as much carbon dioxide than water at 20°C. Dissolved carbon dioxide will be driven out of warming oceans to provide a positive feedback; as the oceans become warmer, the atmospheric carbon dioxide concentration increases, leading to still warmer oceans, and so on. However, the oceans, being in contact with the atmosphere, remove heat that would otherwise be available to further warm the atmosphere. The oceans thus act as a sink for heat and can delay the warming of the atmosphere. In rough terms, a warming atmosphere coupled to the upper wind-driven part of the oceans, reaches temperature equilibrium in two or three years. However, if the heat of the atmosphere can penetrate more deeply into the oceans, say 500 meters, then warming of the atmosphere caused by changing levels of trace gases is delayed by 20 to 30 years. Understanding the process by which heated ocean waters are mixed is thus critical to determining how fast the atmosphere warms up as industrial gases are added.

The indirect affects on the biosphere are similarly complicated. Changing climate can counteract the mitigating effects of increased photosynthetic activity caused by greater carbon dioxide levels. Increased cloudiness reduces the availability of light, while hot, dry periods stress plant systems and reduce total biological productivity. The response of the biosphere to the indirect effects of changing atmospheric composition is exceedingly complex, and only preliminary research has been undertaken to study these responses.

Before proceeding with a more detailed consideration of the role of the oceans and biosphere in both affecting climate change and being affected by climate change, I will summarize my view of the results of the many studies using computer simulation of a changing atmosphere, emphasizing those changes relevant to the oceans and biosphere. While I adhere to custom in referring to a doubling of atmospheric carbon dioxide, effects should be anticipated with lesser alterations of carbon dioxide concentration. Indeed, a present puzzle is why observable effects have not been clearly perceived as a result of changes that have already taken place. The following assertions are indicated by climate models and are listed more or less in order of what I consider their degree of reliability.

- A doubling of atmospheric carbon dioxide concentration will increase average surface temperature 1.5 to 4.5°C with a most probable range of 2 to 3°C.
- Temperature change due to increases in other trace gases, particularly tropospheric ozone and methane, can be anticipated to equal or exceed the effect of carbon dioxide on average temperature. Thus the average temperature 50 years from now will be 1.5 to 2.5°C warmer than today.
- Warming will be greater than average at the higher latitudes and less so in the tropics.
- The overall hydrologic cycle will intensify with greater evaporation over both the oceans and land and greater precipitation at high and low latitudes.
- At mid-latitudes the central regions of the great land masses of North America and Eurasia will tend to be drier.

These generalizations, are based on examination of computer simulations, and are in general consistent with the results of the analysis of past climates. However, temperature fluctuations of several degrees have not been observed in historical times and only incomplete geologic records are available to study past large shifts in climate.

Far less certain than the above judgments are the answers to three key questions; the answers to which are essential if we are to estimate biospheric response to climate change:

- Does the rise in mean temperature produced by carbon dioxide and other trace gases occur mainly in summer or in winter?
- Does the rise in temperature occur mainly by day or by night?
- Does the rise in temperature increase or diminish the magnitude and frequency of damaging extreme weather conditions (i.e., hurricanes, droughts, destructive frosts, etc.)?

Seasonal temperature variations have been studied with puzzling results. General physical considerations suggest that the warming should be greater in summer, since wintertime solar radiation is less and there should be less of an effect on reradiated thermal energy. Much simplified heat budget models support this conclusion. However, changes in snow cover and in ocean circulation make the problem far more complicated. Computer models indicate an enhanced warming in winter, but the issue remains uncertain. The day-night cycle in an altered atmosphere is unexplored.

The problems of statistically modeling extreme changes in climate activity are formidable, but it is the extremes that are of major concern to agriculture. The questions of whether there will be increased or decreased frequencies of drought, of early or late frost, of hurricanes or other storms, are all central to examining the viability of society in the future. No reliable forecast can be made, however, analogies with other complex systems may provide guidance. The earth's climate has, over the centuries, reached a quasi-equilibrium state dictated by the past atmosphere, distribution of land and sea, and all the parameters that go into determining climate. Over a period of a few decades, the atmospheric parameters have been undergoing significant change. The overall system will respond by attempting to reach a new equilibrium state, which itself is gradually changing as atmospheric composition is altered. The system as a whole may undergo wide excursions in search for the equilibrium situation, leading to more frequent "extreme" events. Such behavior is known in other computer modeled complex systems which, however, are vastly simpler than the atmosphere. On general principles, it might be expected that the atmosphere, being perturbed from a defined quasi-equilibrium state, will undergo wider swings than relatively simple models would indicate, as it searches for a new, and slowly but continually changing equilibrium state. While such general arguments can be advanced to support the notion that weather will be more irregular in epochs of changing climate, there is no hard evidence available as to what the day-to-day and year-to-year fluctuations in weather will be.

I now consider in slightly greater detail the roles of the oceans and biosphere in modulating future climate. The moderating influence of the ocean depends on the rate at which heat and carbon dioxide can be transferred from the near surface layers to the deep ocean. Deep ocean mixing takes place primarily through the operation of "polar pumps." For example, in winter in the artic, the freezing of sea ice leaves beneath the ice denser, saltier water as fresh water is taken up in ice formation. This cold, salty, and dense water sinks in wintertime in the Atlantic, mainly in the Norwegian and Labrador Seas. A similar source of deep water is found in the Weddell Sea area of Antarctic. On the average, water that sinks in the winter and spring returns to the surface several hundred years later; the journey of these water bodies has been traced out in part by using radioactive tracers. The deep water eventually moves to the surface. In upwelling from depths, the water carries toward the surface nutrients that have rained down as waste of prior biological activity. The nutrient rich rising water can then support vigorous biological activity, including large fish population.

The polar pumps also drive the horizontal poleward flow of near surface waters carrying tropical heat to the higher latitudes. The polar pumps thus exercise a great influence on weather by redistributing heat from equatorial regions to higher latitudes, and on oceanic biological activity by recycling nutrients that would otherwise be deposited in deep ocean sediments.

A disruption of the polar pumps could have widespread consequences to ocean water circulation, to weather, and to biological activity, including ocean fisheries. In the Norwegian Sea, the waters are saline because of evaporation in tropical regions and northward transport of the surface waters. Wintertime cooling alone, unaided by freezing sea ice may be sufficient to increase water density and drive the pump. Increased warming of the high latitude regions induced by trace gases would remove sea ice, exposing the waters to winter cold and thus possibly maintaining the pump action. But the removal of sea ice does lessen salty brine formation. The net balance between substaining the pump in the absence of ice through direct cooling of the waters, and disrupting the pump through lessening of near surface water salinity is not known.

I have dwelt on the polar pumps both because of their importance and because their functioning illustrates the complexity of the oceans' response to climate change. If the pump is maintained in the absence of sea ice, then a larger fraction of the ocean is available to remove heat from the atmosphere, and the oceans are more effective in delaying atmospheric warming. Alternatively, atmospheric warming may disrupt polar pumping action. Such a disruption would have major consequences to weather and to biological activity in the oceans.

In order to predict reliably the response of the oceans to increasing atmospheric concentrations of carbon dioxide and other trace gases, and how this response will in turn affect atmospheric concentrations and heat balance, the chemistry of carbon--both organic and inorganic--in the ocean must be considered. Numerical models have begun to treat in limited detail the problems of ocean circulation; the questions of chemistry and biology of the oceans are only now beginning to receive attention.

While our understanding of the oceans' response to atmospheric alteration is sketchy, we are on even less secure ground in attempting to anticipate changes in the biosphere. Most research has quite naturally focused on the impact of climate change on food and fiber production. Less attention has been given to questions of the global ecologic response and how the biosphere, together with the oceans, might modulate future climate change. For example, one could advance the hypothesis that the biosphere and oceans provide a mechanism for negative feedback so that climate changes are minimized. In this hypothesis, initial increased carbon dioxide levels promote photosynthesis on land, storing part of the carbon released by burning of fuels in plants. The hydrological cycle is stimulated, leading to greater erosion and the washing of mineral nutrients to the oceans. Higher nutrient and carbon dioxide levels in the oceans increase marine biological activity, particularly in the shallow seas. Carbon placed in the atmosphere through the burning of coal, oil, and natural gas is returned to the sediments as detritus of the enhanced biological activity in the oceans. In this way, the oceans and biosphere provide a brake on warming, at least that due to carbon dioxide. While some will find such a hypothesis plausible, and even argue that such mechanisms were at work long ago in geologic time, such speculation does not provide a reliable forecast. The time scales for the various steps are not known, the degree to which the hydrologic cycle intensifies can only be roughly estimated, the increase in erosion and oceanward transport of nutrients can only be guessed at, and so forth. None of these uncertainties can be significantly reduced in a few years, even with much enhanced research efforts. Geologic and historical records do provide a guide, but that guide is imperfect in the sense that temperature changes of a few degrees over decades have never been observed. Changes of this magnitude are anticipated, thus we are embarking into unchartered territory. Judgments of the future will be uncertain, and the uncertainty can only be reduced by research efforts that themselves will take decades. In view of continuing uncertainty, I would advocate caution in taking those steps that are most likely to reduce future climate shifts.

The impact of climate change on agriculture presents a simpler problem than that of global ecology in the sense that resulting changes in managed ecosystems are unlikely to affect climate through some sort of feedback system. A potential exception, sometimes discussed in the past, is a massive reforestation program, with the forests designed specifically to take up carbon released into the atmosphere. While in principle, this solution to the carbon dioxide problem is possible, probability of implementation is extremely small given the vast land areas required and the many competing demands for land use.

Estimating future agricultural productivity is complex because changes will result both from the direct impact of heightened atmospheric carbon dioxide levels as well as changes in climate. The direct effects are not certain. Plants can be categorized according to their response to carbon dioxide during photosynthesis. Most of the crops that feed the world--12 out of 15--increase photosynthesis with increasing carbon dioxide. The remaining three, of which corn is principal, increase but at a lesser rate than the others. Weeds also increase photosynthetic rates with increasing carbon dioxide, but most of the weeds belong to the second category of plants that respond less positively to increasing carbon dioxide. Overall, the direct effect of increasing carbon dioxide levels--not considering indirect effects--would be to enhance the productivity of agriculture. Most crops would grow better while competing weeds would be less favored.

Direct effects of higher carbon dioxide levels include an additional favorable consequence to agriculture: As carbon dioxide in the atmosphere increases, most plants show a decreased loss of water. Since water transpiration is an important feature of the hydrologic cycle, the cycle itself will be affected by the plants' response to carbon dioxide. As a result, high carbon dioxide levels will increase the resistance of many crops to drought. A warming climate then, even if it is accompanied by drier conditions, can lead to enhanced productivity in some circumstances. This and other conclusions, with respect to the direct effects of carbon dioxide rise, remains uncertain because experimental evidence, with respect to the influence of carbon dioxide increase on plant growth, is limited. Most experiments have been conducted under laboratory greenhouse conditions. Whether preliminary conclusions based on these types of experiment hold under real field conditions remains unclear.

In some ways, evidence of crop response to indirect effects of changing atmospheric composition is stronger. Historical data can be used to track the response of individual plant species to changing weather conditions. Yields of corn or wheat as a function of changing weather can be determined by adjusting the overall change for improvements in pest control, fertilization, and irrigation. Data taken over the past 50 years can be used as a reference to estimate future productivity under changed climatic circumstances. These data provide certain broad guides. For example, an increase in average temperature of 1°C has the effect of lengthening the growing season by ten days. Such generalizations are difficult to apply because each crop will respond differently, and the local conditions of soil quality and weather may overwhelm general trends. Despite these qualifications, statistical analysis of historical data for agriculture in North America indicate that the indirect effects of changing atmospheric composition will lower agricultural productivity. (Only scattered data are available to estimate the change in agricultural productivity for areas other than North America.) As an example, consider the Red River Valley which includes eastern North Dakota and western Minnesota. Spring wheat is a major crop. An increase in temperature of 1°C in April will tend to increase productivity, as planting can come earlier in the year. On the other hand, a 1°C warming in June or July will increase the frequency of hot days over 32°C and the yield will be decreased, since in the Red River Valley, spring wheat heads in June and July and hot spells during heading decreases yield. The expected decrease in precipitation will combine with more frequent hot days to lower yields. The combined effects of a 10% decrease in precipitation in summer, together with higher frequency of hot days in June and July, will lead to a 7-10% decrease in yield, based on a statistical analysis of historical data. In other areas, and for different crops, the expected reductions in yield will differ. The important point is that the decrease in yield to be expected from the indirect effects of climate change are probably significantly greater than the direct effects of increased carbon dioxide. Such estimates of future productivity have serious faults. Increasing stress due to indirect effects of climate change will increase vulnerability to pathogens and insects, thereby reducing productivity. However, as climate conditions change, new varieties can be planted. More resistant to the hotter, drier climate, these varieties may ensure that productivity is maintained. It is unlikely, based on past experience, that genetic improvements can result in higher yields than present. At best, varietal improvement would maintain productivity rather than continuing to increase it, as has been the historical case.

I hope this discussion provides a view, even if limited, of the very large uncertainties connected with attempting to forecast future agricultural productivity in North America. It would appear that in the near term, up until the turn of the century, the combined direct and indirect effects on agricultural productivity are modest, some positive and some negative. In this time period, past practices of adapting crops and husbandry to an environment that is slowly changing will probably maintain current productivity. Beyond the year 2000, as climate changes become larger, the linear projection of the past may no longer provide adequate guidance. Concerns about this time period are heightened, if indeed the changing atmosphere produces greater and more frequent climatic extremes.

In looking at actions that might be taken now by government, several general points provide guidance. Many of the climate-altering trace gases can be controlled without major economic repercussions. Freons are not an essential economic element in any society. Nitrogen oxides and carbon monoxide that lead to higher ozone levels can be controlled, but at a cost. However, carbon dioxide is the largest single contributor to climate warming. No foreseeable technology can deal with the vast quantities, and distributed sources of that essential byproduct of the burning of coal, oil, and natural gas. The current and future importance of carbon-based fuels is underlined by projections of future energy sources. For example, the Gas Research Institute projects an increase in energy use in the United States of 30% between now and the year 2010. Carbon-based fuels are expected to provide 91% of this energy, about the same fraction as today. However, coal increases 44% in these projections, and since coal releases more carbon dioxide per unit of energy delivered than any of the other carbon-based fuels, carbon dioxide emissions will increase more rapidly than the rate at which energy use increases. Since historically, introduction of new energy sources takes at least 50 years, the only conceivable way of reducing carbon dioxide emission is through increased energy efficiency.

In turning to governmental actions that may alleviate the effects of climate change, I start with the premise that the consequences of climate change are so uncertain, the only prudent course in the foreseeable future is to undertake measures that minimize those changes without being disruptive of economic growth. I recognize that draconian measures are not possible, only gradual, incremental adjustments are feasible in our complex society. Given realities, I rule out my favorite first step, a user charge on carbon dioxide emissions designed to capture the societal costs of carbon-based fuels. Instead, I raise four interrelated issues on which the legislative branch of government can have a significant influence, even though this committee does not have major responsibility for all.

- Fuel efficiency standards for automobiles and light duty trucks.
- Clean Air Act amendments and acid rain proposals.
- Environmental Impact Statements.
- Research.

The maintenance and future tightening of standards for fuel efficiency in automobiles has real, as well as symbolic implications in dealing with the problem of climate change. Fuel standards were set in place when the question of energy shortfalls were critical. These questions have receded in importance as available world oil has become more abundant. Since the transportation sector of the economy is a major source of carbon dioxide, and indirectly of other greenhouse gases, the relaxation of standards will only increase the United States' contribution to worldwide climate problems.

In considering possible amendments to the Clean Air Act, the question of acid rain will be of great importance. Acid rain and climate change initially would appear to be distinct, independent issues. In fact, they are closely coupled since trace gases such as ozone, which are of importance to the greenhouse effect, are critical to questions of acid rain; climate changing trace gases and acid deposition are inseparably linked through a common chemistry. These links are so important to future legislative actions that I have prepared a detailed discussion of them and request that this paper, "Climate Change and Acid Rain," be included in the record of these hearings.*

The importance of the link between climate change and acid rain can be illustrated by example. A precursor of acid precipitation is sulfur dioxide, produced in large part by burning coal to fuel electrical generating plants. Sulfur dioxide requires a strong atmospheric oxidant to convert it to sulfuric acid; ozone is a principal oxidant. By reacting with ozone, sulfur oxide removes one of the trace gases significant to climate change. Thus, reduction of emissions of sulfur dioxide alone, without reductions in oxidant forming compounds, may accelerate climate change. An important side issue is that ozone itself may be an important cause of forest damage usually attributed to acid rain. Whatever the correct situation is, this example illustrates that legislation leading to measures designed to ameliorate one problem may worsen others. Because of these indirect interconnections, it is essential that amendments to the Clean Air Act be drafted with a clear view of those consequences we now know something of. The paper accompanying my testimony provides an overview of some of these important interconnections.

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*The paper referred to has been retained in committee files.

I hold an almost nostalgic view of the National Environmental Policy Act, and the Environmental Impact Statement procedure which it established, having been involved both in the formulation of the legislation and the later implementation of the impact statement procedures. To many, the purpose of Environmental Impact Statements was not to provide a further exercise in bureaucratic futility, which the process unfortunately has become, but to call attention to actions planned by government that might have significant environmental impact. Actions that would affect future global climate certainly would fall in this category. The impact of any single action produces only incremental change but the sum of these changes can be significant. The highlighting of potential climate impacts in Environmental Impact Statements could provide a means of keeping policymakers and the public aware of climate problems. I would urge that a future congressional review of the Environmental Impact Statement procedure, which is badly needed, would focus attention on the need to examine the longer-range issues under discussion today.

Increased support for research is always a favorite theme of scientists. The problems of climate change are of such complexity, and of such long-term importance to society, that I believe a larger fraction of available research monies should be devoted to the many facets of climate change. Individual scientists will have their own views of which areas deserve priority attention, and these views deserve respect. Today is not the time to list these priorities, but to emphasize that the broad area of climate research would benefit greatly by increased financial support. Research will incrementally reduce uncertainty about the future evolution of climate and its consequences, but it will not eliminate uncertainty. Those with responsibility must make judgments, even when knowledge is fragmentary. As we move into an unchartered territory where climate changes significantly in mere decades, I hope our moves are cautious.

RESPONSES TO GREENHOUSE GAS INDUCED CLIMATE CHANGE

Statement before the Senate Subcommittee
on Toxic Substances and Environmental Oversight

by

Dean Abrahamson
Professor of Public Affairs
Hubert Humphrey Institute of Public Affairs
University of Minnesota.

Washington, D.C., 10 December 1985, 10:00 a.m.

Mr. Chairman and Members of the Committee:

I appreciate this opportunity to present my views on the subject of possible governmental responses to global climate change as a consequence of the continued atmospheric releases of greenhouse gases.

THE ISSUE

About a hundred years ago the Swedish scientist, Svante Arrhenius, pointed out that increasing the carbon dioxide concentration of the atmosphere could lead to warming of the earth's atmosphere. By the mid-1900s reliable measurements were being made of atmospheric carbon dioxide and some scientists suggested that global warming could be important in the near future. Within the past few years evidence has been accumulating showing that a number of other greenhouse gases are, in the aggregate, at least as important as is carbon dioxide. There is now a consensus 1/ within the involved scientific community that should emissions of carbon dioxide, and the other greenhouse gases, continue on current trends, the planet would experience a warming within the next few decades which is greater in magnitude, and more rapid, than any experienced since the ice ages.

The impacts of such climatic change probably scale with the size and rate of change in average global temperature, and hence

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1/ The most recent expression of this consensus is the "Conference Statement" from the 9-15 October 1985 "Assessment Conference on the Role of Carbon Dioxide and Radiatively Active Constitutents in Climate Variation and Associated Impacts" sponsored by WMO, UNEP, and ICSU and held in Villach, Austria. I will refer to this conference statement from time to time throughout this testimony.

with changes in the large scale circulation of the atmosphere. Were climate changes to be small, and to occur sufficiently slowly, they could be relatively non-disruptive. Climate has changed before. In response, populations have migrated, forests and other ecosystems have moved and changed in species composition. But these changes have been slow compared with life spans of trees or of humans. We are now facing the imminent prospect of a climate change greater than any previously experienced by civilized man taking place in a time short compared with human, social, or ecological time constants, and leading to changes that have a reasonable chance of being quite disruptive. The greenhouse effect of atmospheric carbon dioxide and the other greenhouse gases has, therefore, become a serious question for society. Because of it, we are probably on the threshold of a profound world climate change.

Carbon dioxide is the most important of the greenhouse gases. It is produced as a by-product of several human activities, the most important being the combustion of fossil fuels, the destruction of standing forests, and the oxidation of other biotic pools of carbon. There is no practical means for preventing the release of carbon dioxide other than by curtailing the activities which lead to its production. Once in the atmosphere its effects are irreversible in time scales of interest, tens of human life spans. Until the late 1970's carbon dioxide was thought to be the only greenhouse gas of much importance with regard to the future state of the climate. Hence, the problem seemed relatively uncomplicated, to be resolved through adaptation to some warming, and limitation of the remainder through the deployment of energy sources which produce no net carbon dioxide -- solar, or nuclear. When energy consumption growth rates were reduced following the oil price shocks of the 1970's, concern about carbon dioxide was further reduced as it seemed that we had more time to respond with reduced CO2 production rates.

The situation changed with the recognition that concentrations of several other radiatively active gases are increasing in the atmosphere, and, at present rates of increase, will exert a considerable influence upon climate. With the addition of the non-CO2 gases, the magnitude of the potential global warming at least doubled, and the time which was seemingly gained because of reduced fossil fuel growth rates evaporated. Not all of the other greenhouse gases may be amenable to control. Some of them, for example the Freons, are produced by only a limited number of industrialized nations, have applications which are easily eliminated, or have known substitutes. However others, for example methane, seem related more to global population pressures than to industrialization, and are probably extremely difficult to limit. Hence, rather then lessen the pressure for control of carbon dioxide emissions, the prospect of significant warming from these other gases increases the pressure for action on carbon dioxide, and hence on fossil fuel usage.

Greenhouse gas induced climate change confronts society with a major challenge. Policy changes will be required if we are to avoid, or substantially delay, the climate change. On the other hand, the anticipated climate changes would require changes in virtually every sector of the economy, and may doom a large portion of our environmental heritage. This requires a reassessment of present policies. Soon we must decide whether to reduce the use of all fossil fuels, to burn coal as the principal way to meet future energy needs, and whether or not to continue destroying our forests.

Decision cannot be avoided. Implicit even in a decision to temporize, to wait and see, is acceptance of large changes in climate. A decision to continue the activities which are leading to emissions of the greenhouse gases is a decision to conduct a global experiment which carries unprecedented risk.

A FIVE DEGREE CELSIUS WARMING IS PLAUSIBLE

The Villach conferees concluded:

> While some warming of climate now appears inevitable due to past actions, the rate and degree of future warming could be profoundly affected by governmental policies on energy conservation, use of fossil fuels, and the emission of some greenhouse gases. . . .
>
> If present trends continue, the combined concentrations of atmospheric CO2 and other greenhouse gases would be equivalent to a doubling of CO2 from pre-industrial levels possibly as early as the 2030's. . . .
>
> The most advanced experiments with general circulation models of the climatic system show increases of the global mean equilibrium surface temperature for a doubling of the atmospheric CO2 concentrations, or equivalent, of between 1.5 and 4.5 degrees C.

Thus, the "some warming" to which we may already be committed, possibly as early as the 2030's, may exceed four degrees C using the upper limit of temperature response. If we decide to ignore the evidence and do nothing to decrease releases of the greenhouse gases, the warming could increase to between four and nine degrees (one additional doubling) within the next century.

Before suggesting appropriate policy responses, some obvious questions should be examined.

Is the Scientific Assessment of Temperature Response Valid?

There is no way to answer this question in a scientifically valid manner as there will be no proof until the warming is observed.

However, it should be noted that the estimates of temperature response have not been lowered, following the many climate model reviews of recent years. On the contrary, estimated temperature changes have steadily increased as the importance of non-carbon dioxide greenhouse gases have been recognized. In 1975, the warming that was expected in the next century was only about 2 degrees Celsius. By 1980 it had increased to about 4 degrees Celsius, and, today a global warming of 4-9 degrees Celsius, or more, can be defended as possible within the next century.

Will the Source Terms Continue to Increase?

Carbon Dioxide

Future rates of release of CO2 are an artifact of political decisions, and not an issue that can be addressed by scientists. It is simply a matter of society's willingness to continue to release greenhouse gases in the face of strong, and growing, evidence that in doing so it is risking major climate change.

Carbon dioxide releases scale with: fossil fuel use, the dominant term; the mix of fossil fuels; deforestation and other changes in land use; and feedbacks between warming and carbon dioxide production. Growth rates in energy consumption have dramatically decreased since the mid-1970's from the historic four to five percent per year to a current level to less than two percent per year. Supply-oriented energy policy studies, however, all include a growing dependence on coal and the other solid hydrocarbons. Coal use produces significantly more CO2 per unit energy than does oil or natural gas. Any commitment to fossil fuel derived synfuels will further compound the carbon dioxide problem, locking us into a source of liquid fuel which involves a CO2 production two or three times as much as is produced per unit energy derived from natural gas.

While carbon dioxide release from the fossil fuels is relatively well known, that from biotic sources is poorly understood. It is probable that CO2 production from deforestation is between one and four billion metric tons per year. The biotic metabolic response to increasing levels of CO2 or to a warmer globe is not well known. There is some evidence from laboratory experiments that the rate of carbon fixation increases with increasing levels of CO2. However, there is no unequivocal field evidence that more carbon is being stored in the biosphere, and there is abundant evidence that forests are being destroyed both by intentional deforestation and because of the effects of other toxins, e.g., acid deposition.

Erosion, deforestation, and warming all lead to the release of sequestered carbon. Respiration increases about three-fold per ten degree C increase in temperature. Hence, a warming of one degree increases biotic respiration by 20 to 30 percent. There are vast pools of carbon in biota and soils which are available for release -- some estimates as high as 2,000 billion metric tons, three times as much as is now in the atmosphere. On a much longer time scale, warming of the oceans will result in the exhalation of very large amounts of oceanic CO2.

Other Greenhouse Gases (OGG)

The chlorofluorocarbons, chlorocarbons, and fluorocarbons are released to the atmosphere as a consequence of industrial manufacturing activities, spray can aerosol use, leakage from landfills, and other activities. Of the many manufactured gases, two -- CFC-11 and CFC-12 -- dominate with regard to the expected effect. The warming from prospective increases in concentrations might approach 0.4-0.8 degrees Celsius, and hence represents a significant contribution to the total. The industrialized countries produce most of these gases, and emissions are still small enough that controls can probably be imposed on global emissions. Most estimates suggests that controls could be imposed on CFC-11 and CFC-12 with relatively low cost to society, making these two gases prime targets of opportunity for preventive action.

The same probably cannot be said of gases that are emitted as a direct consequence of global agricultural expansion, and of global population increase. Surface emission of methane, for instance, results from anaerobic oxidation of organic matter in rice paddies, flooded fields and swamps, as well as from enteric fermentation. Nitrous oxide is probably released to the atmosphere through the denitrification of agricultural fertilizers. Increased ozone concentrations result indirectly from surface emission of carbon monoxide, half of which may be produced through tropical deforestation, much of which is said to be related to population and agricultural expansion. With world food needs projected to increase over the next 4-5 decades, it is difficult to imagine successful intervention with regard to the release of these gases.

Fossil fuel sources account for the remainder -- perhaps as much as one-third -- of the expected OGG warming. Combustion of fossil carbon releases carbon monoxide and some methane. Present estimates suggest that about half of anthropogenic emissions of carbon monoxide result from fuel combustion, much of which is from the transportation sector. In addition, the expected surface warming from carbon dioxide and the OGGs is thought likely to increase methane emission from existing flooded fields and from ocean sediments. Since more than half of the expected surface warming is carbon dioxide or ozone related, a good deal of this extra methane emission (sufficient to increase concentrations about 2-3 times present levels) can be laid at the door of fossil fuel use, for which the prospects of control are promising.

What are the North American climate changes with a 5 degree warming?

Considerable inference is often drawn from reconstructions of the Altithermal period (5,000-7,000 years b.p.) in discussions of a warmer world. That period may be a valid analogue to the most optimistic case of a warming of two degrees C or less. We may well be concerned, however, with a significantly greater warming. In particular, the evidence implies that within 60-80 years, and possibly within 50 years, planetary temperatures will increase 4-5 degrees Celsius, or about the same amount thought required to melt the floating pack ice in the Arctic Basin.

While not a great deal is known about the particulars of climate under such conditions, some knowledge can be extracted from climate model results, which consistently reveal considerably warmer (5-7 degrees Celsius) and drier conditions in the center of the North American continent. Model calculations typically give spring-summer soil moisture reductions of 10-20 percent or more, along with corresponding reductions in summer runoff and streamflows. Similar evidence can be extracted from climates of the distant geological past, especially those of the last part of the middle Tertiary and the late Tertiary, 5-20 million years ago, during which planetary temperatures were probably 4-6 degrees warmer than now. Late Tertiary conditions seem to have involved significant inland aridity, with 600-1300 km displacements of the northern boundaries of arid, subtropical, and temperate climates.

What, then, might climate of the interior of the continent be within 60-70 years? First, it will be much drier, with higher temperatures increasing evaporation far more than precipitation, which some, though not all, models results suggest might actually fall. Precipitation declined during the Altithermal and the Eem Interglacial (1.0-1.5 degrees Celsius warmer than now), especially in the southern High Plains, the Great Plains, the Upper Midwest, and California. The frequency of extreme spring and summer temperature and moisture events -- i.e., heat waves and drought -- should significantly increase as average temperature and moisture availability conditions approach levels that today are thought extreme. For example, 95 degrees Fahrenheit, which is frequently taken as an deleterious peak July daily temperature for modern corn production, frequently would be exceeded throughout at least half of the present corn belt. In addition, summer runoff will decline with an earlier snowmelt and enhanced evaporation, and this will reduce summer streamflows and lake levels. Reduced summer runoff should reduce groundwater recharge rates. And, the atmospheric burden of wind blown dust should significantly increase over the US, since drier conditions favor enhanced wind erosion of Great Plains soils.

On the other hand, the southern and eastern coasts probably will be much wetter with an increase of tropical storms, since hurricane incidence tends to vary with the warmth and extent of tropical seas. Sea levels also should be higher -- as much as 2 meters higher -- than now, and this, along with increased storm incidence, should make storms that presently are considered only one-in-one-hundred-year-events more frequent.

Impacts of the Scenario

Rather than attempt a detailed accounting of impacts under such a scenario, let me note some impacts which seem likely.

Activities and resources which much of the present US environmental legislation is designed to protect would be in jeopardy. In the mid and far west a drier climate would influence the viability of forests at the margins of present steppe climates, and hence the viability of various national forests and wilderness areas. Reduced lake levels and stream flows would affect freshwater ecosystems, and, for instance, make the preservation of endangered aquatic species quite difficult. They would also make difficult adherence to present water quality standards, which would need to be tightened with less dilution of water-borne pollutants. In the north, warming and drying would threaten peat bogs, marshes, and prairie potholes, and the species dependent upon them for breeding grounds or habitat. On the coasts, a two meter rise in sea level would inundate most salt marshes and coastal wetlands, push barrier islands further toward the present coast, and contaminate coastal aquifers.

One could do a quick accounting of the ecological or environmental resources that would be affected, and it turns out to be quite long, including, for instance: endangered species; habitat preservation; coastal zone protection; all legislation affecting inland rivers and lakes, dams and water diversion; groundwater protection (hence concern over hazardous wastes); wind-driven soil erosion and desertification (and hence western Federal land management and reclamation). Given the scenario, most of the impacts would be negative, and, in the extreme, though still plausible, worst case, would undo much of the present effort at environmental preservation.

Economic activities that are temperature and moisture sensitive, for example agricuture, also would be affected. It is impossible to predict with any degree of confidence the yield impacts that are possible, given the many structural and technological changes which the agricultural sector is presently undergoing. However, present agricultural sensitivity to climate -- as evidenced in yield responses to heat waves and drought -- strongly suggests that negative impacts would be registered. Of course, it has often been suggested that increased ambient carbon dioxide, apart from its climate effect, is beneficial to plant growth and that this will compensate for the climate changes. If, however, we look back to the Tertiary period we find accumulating evidence for elevated carbon dioxide concentrations (maybe to

600-800 ppmv), and evidence, not of significant drought resistance in plants, but of dessicated soils and plant life characteristic of arid regions. Much work needs to be done, but the available analysis suggests that a more sober view of the agricultural/forestry/grazing situation is in order than constitutes the present accepted wisdom.

So, for what activities is there a reasonable chance of negative impacts? A short, and admittedly incomplete, list would include: grain, vegetable and animal agriculture; fiber production; any activities dependent upon in-stream rivers flows, for instance electricity and synfuels production, urban water uses, barge transport, and agricultural irrigation; many forms of recreation; coastal development, fisheries, and settlement patterns; and forest-related industries. Water scarcity in southern California, as well as fire incidence, would be of special concern upon realization of the five degree scenario. This concern stems from the very dense pattern of regional population, the size of which makes any major impacts -- including outward migration of people -- a significant national problem. The National Academy of Sciences suggests reductions in streamflows in the Colorado River and in the rivers of northern California of as much as 40-60 percent with only a two degree Celsius warming and 10 percent precipitation reduction. This study suggests considerable stress between anticipated demand and supply. From where will replacement water come? What will be the costs of movement? Can it be moved, and, if not, what are the implications? I do not know the answers to these questions, but simply suggest that they are a matter for no small national concern.

Which Policies Would Work to Prevent a Five Degree C Warming?

Recent work has shed considerable light on energy policy options that can have a major influence on carbon dioxide production. 2,3/ Given the dominance of the fossil fuel term in future increases in atmospheric carbon dioxide concentrations, my comments will concentrate on such energy policy options. Fortunately much work over the last decade has made clear the physical dimensions of the energy problem. Of the many things that have evolved from this work, one is of particular importance: the absolute centrality of the efficiency of energy use in both the short term and the long term energy picture. Obviously, energy consumption is closely related to the efficiency of use; a significant increase in the efficiency of use would result in the need for much less energy consumption to achieve a higher level

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2/ Jose Goldemberg, Thomas B. Johansson, Amulya Reddy, and Robert Williams, "An End-Use Oriented Global Energy Strategy", Annual Reviews of Energy 10, 1985, pp. 613-688.

3/ D. J. Rose, M. M. Miller, and C. Agnew, "Global Energy Futures and CO2-Induced Climate Change", MIT, 1983.

of goods and services. The efficiency of use has been rapidly increasing in response to both market and non-market forces: about one percent, or slightly more, per year in nearly all end-use sectors in the industrialized countries over the period 1973-1984. Since this is about half of the rate of increase in fossil fuel use usually projected for well into the future, long term continuation of this increase in energy productivity would have the same effect as policies which reduce the long term rate of increase in energy use by half.

The potential for continued increase in end-use efficiency appears to be extraordinarily large. Efforts to estimate the size of this reservoir suggest that it is sufficiently vast that, were it to be fully and immediately exploited, atmospheric carbon dioxide concentrations (excluding the biotic source) could be constrained to the 380-390 ppmv range at 2030, which implies a negative annual rate of growth in carbon dioxide emissions. Hence, the first and most important aspect of a preventive strategy should entail as full a realization of this potential as possible. Some of this will occur as a result of ongoing evolution of industrial economies. However, active policy measures, for instance those that insure wide availability of information on efficiency improvements or which protect past gains from temporary reductions in oil and other energy prices, are sure to be required.

The other critical lesson learned over the past decade relates to sensitivity of energy use to price and the importance of proper pricing of energy products. Much work has been done on the former, showing declining energy use with increasing energy prices. The most justified kinds of pricing innovations at present probably involve full internalization of the non-greenhouse environmental costs of coal and shale oil combustion into the selling price of coal. Unlike the greenhouse costs, these external costs are fairly well known, and should be internalized into the selling price regardless of the prospect of threatened climate changes. Model calculations imply that full internalization would have an effect of the same order as the effect of historic increases in energy end-use efficiency -- i.e. a reduction in the usually assumed rate of increase in fossil energy use by about half -- and this strongly suggests that purposeful policy actions can bring rates of annual increase to something well under one percent (and atmospheric carbon dioxide to something like 400-470 ppmv at 2050). Since society as a whole bears the environmental costs of coal combustion, correct pricing, beginning with pricing sufficient to correct the acid rain problem, seems in order.

Various other policy options could be considered in efforts to limit increased concentrations of carbon dioxide: general taxation on the use of the fossil fuels; some limited prohibition on the export of coal-use and exploitation technology and more generally of coal exports; elimination of present subsidization of fossil fuel use; expanded funds for research and development for non-carbon energy sources. Of course, to the degree that the releases of carbon dioxide are of an international nature, implementation of policy measures will need to be international in scope. However, in the near term the industrialized countries will continue to exercise a predominant influence in global fossil fuel use, and hence a cooperative approach by the nations of the OECD probably would be a sufficient response over the next few decades.

The latter, obviously, will not be easy to achieve. However, I am much less pessimistic about the possibility of cooperation among western nations than most of my colleagues -- at least until an effort to affect such cooperation has clearly and completely failed. The willingness or unwillingness of western nations to act cooperatively on this problem can only be shown as a result of actual efforts to deal with this problem. Truisms and commonplaces do not suffice, nor should not be allowed to suffice in the face of the prospect of almost overwhelming environmental changes, and their implication for the inhabitants of the planet.

Which Policies Will Not Work?

Adaptation

Planned adaptation assumes that society can ameliorate impacts through technological interventions and timely relocations of production centers: through actions which depend on the rate of change in the environment. Thus, in theory, society might costlessly adapt to changes in climate through sequential changes in capital stocks, so long as the latter are consistent with present rates of turnover in capital stocks; or, society might sustain significant economic loss were such sequential changes infeasible.

Several important characteristics of the adaptive response are of note. First, the characteristic times of national capital stocks are typically very long -- several decades. The time required for major changes in technological systems varies between 20 and 50 years, and probably is between 30 and 50 for water projects. Secondly, the adaptive response requires relatively certain projections of long term local trends in precipitation, drought frequency, wind intensity, and the like, and, at present we do not have them, nor are likely to have them soon. Hence, for all practical purposes, most or all major planned changes in technological or other capital-intensive systems probably involve timescales which are longer than the timescales of economically significant climate changes. For instance, estimates suggest that about two decades, 2000-2020, and slightly more than 1.5 decades, 2030-2045, are associated with each 1.5 degree Celsius increase in surface temperature over the continental US. Each temperature increment of 1.5 degrees C implies a 225 km northward displacement of the cornbelt, an increased peak electrical demand of about six percent, and significant stream flow and ground water storage reductions.

Serious questions, therefore, attach to the adaptive response which to date have been exposed to precious little critical inquiry. Of course, there are traditional non-planned adaptations through which society often adapts to environmental change: changed soil or snow management practices in agriculture; water use controls; strengthened drought relief programs; or enhanced preparedness for floods or hurricanes. However, few such short term adaptations seem well matched to Tertiary-scale climate changes. The new biotechnologies, which are thought likely to be powerful forces of adaptation (and have particularly short lead times), may be an exception, although their availability has yet to be demonstrated, and, like nuclear power, their political acceptability may be in doubt.

In the worst, though still plausible, case (2.5% per year increase in carbon emissions, OGG warming at 300% that of carbon dioxide), the outlook for adaptation is even less hopeful. For instance, consider the carrying capacity in western and midwestern US, regions likely to be much drier with a four degree C global warming, although this cannot yet be affirmed with the degree of certainty required for land-use, water supply, settlement or investment planning. Further, the conditions which would prevail were there changes in global temperature beyond the 4-5 degree Celsius level cannot even be outlined in general terms, to say nothing of the specificity necessary, for example, for planning of major water projects. In such a worst case, a Tertiary-like change in climate could be expected in 45-60 years, upon the heels of which would follow additional warming of several degrees. This places us in a double bind, giving only two to three decades for adaptation to a Tertiary-scale change while at the same time moving us into climate space about which essentially nothing is known and to which preceeding adaptations could be completely mismatched. Obviously, large investments simply are not going to be made under such uncertain conditions.

Wait and See Policies

"Wait and See" policies assume that the time for action is fairly far removed into the future, and that little is lost to society by delaying a preventive response, should such be desirable. The evidence, however, suggests that little time is available for continued study and that action may be needed almost immediately in the most realistic case.

For instance, let us assume for the moment a ceiling on average global temperature increase of five degrees Celsius -- which is rather high, perhaps too high except for the purposes of a thought exercise. If we take such a ceiling and various combinations of different plausible values for the sensitivity of the planet to increased CO2, the contribution of the other gases, and the biotic carbon contribution, we find that atmospheric carbon dioxide concentrations must stabilize at about 390-650 ppmv, with a median value of about 450-500 ppmv. 4/ If we take the median estimate as our target value, then action initiation times can be calculated from the amount of time required for non-carbon energy sources to gradually replace fossil fuel energy sources. For a 500 ppmv ceiling, these action initiation times tend to fall at about 1995, or within a little less than a decade; lower ceilings (450 ppmv) require more immediate action, with rates of increase in fossil fuel consumption required to decline over the next 15 years, and probably turn negative thereafter. If we assume a reasonable amount of decision time, the little time which we have with a 500 ppm ceiling evaporates, as does any appeal in a wait-and-see policy.

CONCLUSIONS

Until the estimates of temperature change rose to levels for which the likelihood of negative impacts could be easily established, there was little prospect for a significant policy response. A viable alternative to the conventional supply-oriented energy policies which unavoidably produce large amounts of carbon dioxide was also needed. Both of these conditions have now been met. We now know enough to justify policy initiatives which delay and limit global warming. It is no longer justifiable to delay action on the basis of arguments about lack of concensus about the general character of future climate change, or need for regionally specific characterizations of future climates, and "winners" and "losers."

In my opinion, the following recommendations are a minimal set of responses justified by the present evidence regarding greenhouse gas induced global warming.

1. Take it seriously.

In the past, most analysts have considered unrealistically small climate changes in assessing impacts -- the best case rather than the most likely or the worst. Those impact analyses have been of limited, or negative, value. Impact analyses which have

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4/ Only in the most optimistic case, in which the lowest values are assumed for all the relevant parameters (i.e., planetary sensitivity to doubled carbon dioxide of 2 degrees Celsius, an ultimate 1.5 degree Celsius OGG warming, 65 ppmv non-fossil CO2), do we get a relatively high ceiling on fossil fuel CO2. For instance, in the case of Tertiary-like ceiling on temperature change (4 degrees C from the preindustrial) the ceiling is about 580 ppmv, giving us about 35 years before action is needed. However, with the exception of this case, the long term efficacy of "wait and see" policies is quite limited.

been limited to the small temperature changes expected in the near future, for example by the year 2000, necessarily conclude that the impacts are relatively small. The results have given the impression that there is no particular need to consider preventive actions, that any consequences are amenable to non-distruptive adaptive response, and that there is therefore no need to take any decision now.

Other analysts have succumbed to the temptation to evoke rapid and unexpected technical developments which will somehow permit reductions in source terms or permit minimally disruptive adaptation to a warmer globe. Some have shown a remarkable ability to pounce on each of the acknowledged uncertainties in the climate models, while accepting Panglossian arguments about possible adaptive devices. These analysts have often further diminished the apparent impacts by heavily discounting the future, or have sought to hide impacts within a context of general societal change, which ostensibly trivializes the impacts expected from climate change.

In addition, impacts on the unmanaged biosphere have been systematically ignored in past assessments. Yet, global warming of the magnitude which is often glibly dismissed as being acceptable will almost certainly doom entire ecosystems -- a large part of our environmental heritage, the preservation of which major legislative and other work of the past two decades has been directed.

Lastly, a warming of several degrees is probably unavoidable, and will further stress a world which is already heavily burdened with water scarcity, increasing erosion and desertification, serious food shortage, and other resource constraints. Some analysts use this to suggest that the effects of global climate change will manifest themselves as simply another stress in an already bad situation, and that the signal will be lost within the dispair of other trends.

In a nutshell, this issue has never really been taken seriously but rather has been consistently discounted through some of the most baroque reasoning that I have encountered in nearly 20 years of policy debates. It is time to take the issue seriously. It is time to use realistic climate changes in assessing impacts. It is time to use realistic estimates of adaptive capabilities. Also, it is time to at least take the possibility of major climate change into account in setting policies on social and economic development, environmental programs, and control of emissions of radiatively active gases.

2. Reduce coal consumption and avoid synfuels.

There is little possibility that society will voluntarily refrain from burning the oil and natural gas. These fuels are perhaps too sweet to resist, and every global energy policy has regarded them as essential as transition fuels, albeit at different rates of consumption.

Acid rain is but the best known of the problems which are now largely laid at coal's door. Coal use, however, is a major contributor to many other serious, global environmental, and economic ills.

A reduction in coal use is critical to the control of carbon dioxide concentrations. It has been shown that if an equilibrium level of CO2 is to be kept below 1.7 times pre-industrial levels (with all oil and gas eventually used up, and half of the CO2 remaining in the atmosphere) then world coal use must decline by 20 percent between 1980 and 2020 and continue declining at the same exponential rate thereafter. Necessary policies to thus limit CO2 include avoidance of economic pressures which drive energy supplies toward coal, and policies which will encourage a continuation of the trends toward more energy efficient end uses. 2/

3. Preserve Biotic Resources.

Deforestation and erosion are tragic quite apart from their climatic implications. Deforestation, and other changes in land use patterns, will accelerate the extinction of both animal and plant life forms, denude soils, alter rates of runoff and sedimentation, and reduce precipitation on tropical land masses. All of these have significant impact for the habitability of tropical zones.

Moreover, the living phytomass of tropical and sub-tropical forests contain about half as much carbon as is now in the atmosphere. While not as potentially large a source of carbon as the fossil fuels, a release which would increase atmospheric CO2 by at least 40-50 ppmv seems likely from this source in the absense of some intervention. Considered in the context of the required ambient CO2 ceiling, 450-500 ppmv, the potential contribution from tropical forests is not insignificant, and should be addressed as an important problem

We do not have a good appraisal of the net release of carbon from the biosphere, or of the metabolic effects associated with a warmer, carbon dioxide enhanced, world, although it is clear that warming will also increase respiration rates of all organic matter, including soils, and dump carbon and other greenhouse gases into the atmosphere. What are the time constants for such release? Are we talking about cumulative emissions of tens or of hundreds of billion tons of carbon? Are we irrevocably committed ourselves to a great deal more CO2 than we at present are aware? These are important questions, yet there is very little research funding available to answer them.

4. Fund a program of research and analysis at a level consistent with the magnitude of the potential impacts.

Academics and analysts are fond of asking for more research funding. The Villach conferees are no exception.

I have no quarrel with the content of the statement from the Villach meeting -- but I am disappointed by the lack of emphasis on policy analysis, and on resolution of the many uncertainties regarding the role of the biota, both in contributing to greenhouse warming and its response to that warming. The statement briefly summarizes the state of understanding of this issue, and then passes directly to a plea for policy initiatives to limit production of the greenhouse gases. There is, however a missing step in their analysis -- the nature of the ecologic, economic, and social impacts which follow from the changes in basic climate parameters and must proceed, and largely justify, suggested policy remedies.

My brief statement to you this morning is also thin on description of impacts -- simply because so little work has been done to illuminate specific impacts, or even to describe the consequences of the new climate regime to which the optimists among us assert we can easily adapt. Without credible impact analyses --- not of climate changes expected in the very short run, but of changes to which, it would appear, we are already committed -- it is unlikely that support can be generated which will enable you and your colleagues in other legislative bodies to adequately respond to the challenge.

One can be convinced that something is important on the basis of scaling arguments. It is now known that a several degree warming, greater than previously experienced in human history, will probably occur other a time which is short compared with a single life span for a tree or a man. It is certain that this will involve major changes in ecologic, economic, and social systems as these systems are all in delicate balance with their environments, which are climate dependent. It is true that no one can now describe the precise nature of those changes -- in part because very few attempts have been made and in part because of the impossiblity of predicting the choices which will be made while the change is going on -- but change there will be.

One might also consider the energy consumption which is necessary to produce the greenhouse gases. Human societies now use, to drive their machines, about ten percent as much energy as is captured by photosynthesis. Photosynthesis is the engine which drives all living things with the exception of industrial man. With another doubling of human energy consumption -- 30 to 40 years at current growth rates -- man will use about one fifth as much energy as all other living things. Energy use is a measure of effect. Such a level of energy use by a single organism can only occur at the expense of other organisms.

It is possible, however, that scaling arguments alone will not be sufficiently convincing to provide the political support needed for policy initiatives having as their goal either a delay, or limitation, of the warming. The means to support impact analyses are badly needed.

RESPONSE TO WRITTEN QUESTIONS FROM THE COMMITTEE TO DEAN ABRAHAMSON

I

QUESTION: You recommend internalizing the environmental costs of fossil fuels to prompt an increase in efficiency. How might we best do this? Would an environmental tax on oil, gas and coal, with tax revenues going into an environmental research and response fund make any sense? Would it be feasible?

RESPONSE: Fuels should be priced as nearly as possible to the marginal cost of new supply, including environmental and other external costs. Regarding the costs attributable to global warming, a minimal first step would be to require that the Environmental Impact Statement process include full consideration of the climate change implications of all development projects. This process will, in fairly short order, result in a much more complete characterization of the social, economic, and ecological impacts which would result from global warming.

Global climate change should not be regarded as an environmental problem and any tax should not be so characterized. While it is certainly true that the global climate is an extremely important component of our environment, the impacts associated with the large, and rapid, global warming which is now an implicit in our energy and economic policies will heavily impact every aspect of our lives.

Consideration of a new tax would suggest an attempt to fine tune a system -- which is not the present state of affairs. What must be done first is to take the global warming issue seriously and at the very minimum strive for informed decision making.

II

QUESTION: We sometimes hear that Canadian provinces might benefit from warmer and wetter weather. Are Minnesota and Montana far enough north, at 45-50 degrees latitude, to share some of that benefit? Will our warming be more than the global average? More or less rainfall?

RESPONSE: While it could be true that Canadian provinces might benefit from warmer and wetter weather, I have never heard it suggested that such a condition would result from the greenhouse effect. The evidence is, rather, that the agricultural portions of Canada would experience warming and drying -- at least during the summer months. The Canadian Climate Board, under the Chairmanship of Professor Kenneth Hare, has published a preliminary assessment of the implications of the greenhouse gas induced climate change for Canada. That study found suggestions of certain benefits for Canada, e.g., lower requirements for heating fuels, it identified the major negative impact as the adverse effect on Prairie Provence agriculture.

As Professor Manabe's statement has made clear, Minnesota and Montana agriculture should experience the same negative impacts as those shown by the Canadian study as they will also experience significantly warmer and drier summers.

The global warming will be strongly latitude dependent, with warming at high latitudes considerably greater than the global average. At 45-50 degrees north, the warming may be between 1.2 and 1.5 times the global average.

III

QUESTION: Is today's society flexible enough to make large scale agricultural changes? Would entire farm communities be disrupted or is there time to transport the water and breed drought resistant crops? What would be the energy demands for storing and pumping vast amounts of water?

RESPONSE: There will likely be major changes in the agricultural sector. It is impossible to predict with any degree of confidence the yield impacts that are possible, given the many structural and technological changes which the agricultural sector is presently undergoing. While contemporary technology has made agriculture more adaptable, in a technical sense, the agricultural sector is probably less less flexible than it has ever been previously because of economic constraints. It is likely that entire farm communities will be disrupted.

Evidence to date suggests significant decreases in yields under warmer and drier summer conditions. Decreasing yields are not the total story, however, as prices may depend on the greenhouse impacts on other countries. Political stress -- both domestic and international -- could also result from major changes in agriculture.

Massive interbasin transfers of water -- for example, from the Great Lakes to the Great Plains, from the Pacific Northwest to the urban Southwest, or from Canada to the United States -- are likely to be expensive, and could even be controversial.

I am not aware of any attempt to estimate the energy requirements for such water transfers, but such a study would be extremely useful and its initiation by the Committee would be welcomed.

IV

QUESTION: Might not genetic engineering protect agriculture over the next 25-50 years?

RESPONSE: It is likely that there are diverse opinions on this question. Advocates for new technologies are sometimes rather optomistic. Others await evidence.

V

QUESTION: If big water projects take 5-10 years to plan, and 5-10 years to build, are we really at a point yet where we need to start those now?

RESPONSE: Many regions of the United States are already experiencing increasing scarcity of water because of depleation of underground water stocks, over commitment of stream flows, and contaminiation of surface and underground water by toxins.

Water projects of the magnitude necessary to cope with the drying suggested by Professor Manabe and other climatologists would likely take considerably more than 10-20 years to plan and build. Compared with what would be needed, the Garrison Diversion Project, for example, would be trivially small.

But again, these studies need to be done. I would urge the Committee to initiate a study of the water replacement implications of the summer drying described by Professor Manabe. It is precisely this kind of information which is needed for informed decision making.

VI

QUESTION: Would you expect forest fire incidence in the upper mid-west to increase?

RESPONSE: Yes, forest fire indicence would be expected to increase with warmer and drier summers.

VII

QUESTION: If we get dustbowl conditions, could the dust itself create a negative feedback by blocking sunlight to the surface?

RESPONSE: Stratospheric particulates are known to produce cooling, but dust in the lower atmosphere does not have a similar effect. Thus, the dust associated with the dustbowl conditions likely to result from continuation of our present policies would not act to counteract the warming caused by the greenhouse gases.

CONFERENCE STATEMENT

FROM THE UNEP/WMO/ICSU

INTERNATIONAL ASSESSMENT OF THE ROLE OF CARBON DIOXIDE AND OF OTHER GREENHOUSE GASES IN CLIMATE VARIATIONS AND ASSOCIATED IMPACTS

VILLACH, AUSTRIA, 9-15 OCTOBER 1985

A joint UNEP/WMO/ICSU Conference was convened in Villach (Austria) from 9 to 15 October 1985, with scientists from twenty nine developed and developing countries, to assess the role of increased carbon dioxide and other radiatively active constituents of the atmosphere (collectively known as greenhouse gases and aerosols) on climate changes and associated impacts. The other greenhouse gases reinforce and accelerate the impact due to CO_2 alone. As a result of the increasing concentrations of greenhouse gases, it is now believed that in the first half of the next century a rise of global mean temperature could occur which is greater than any in man's history.

The Conference reached the following conclusions and recommendations:

1) Many important economic and social decisions are being made today on long-term projects - major water resource management activities such as irrigation and hydro-power; drought relief; agricultural land use; structural designs and coastal engineering projects; and energy planning - all based on the assumption that past climatic data, without modification, are a reliable guide to the future. This is no longer a good assumption since the increasing concentrations of greenhouse gases are expected to cause a significant warming of the global climate in the next century. It is a matter of urgency to refine estimates of future climate conditions to improve these decisions.

2) Climate change and sea level rises due to greenhouse gases are closely linked with other major environmental issues, such as acid deposition and threats to the Earth's ozone shield, mostly due to changes in the composition of the atmosphere by man's activities. Reduction of coal and oil use and energy conservation undertaken to reduce acid deposition will also reduce emissions of greenhouse gases; a reduction in the release of chloro-fluorocarbons (CFCs) will help protect the ozone layer and will also slow the rate of climate change.

3) While some warming of climate now appears inevitable due to past actions, the rate and degree of future warming could be profoundly affected by governmental policies on energy conservation, use of fossil fuels, and the emission of some greenhouse gases.

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These conclusions are based on the following consensus of current basic scientific understanding:

- The amounts of some trace gases in the troposphere, notably carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), ozone (O_3) and chloro-fluorocarbons (CFC) are increasing. These gases are essentially transparent to incoming short-wave solar radiation but they absorb and emit longwave radiation and are thus able to influence the Earth's climate.

- The role of greenhouse gases other than CO_2 in changing the climate is already about as important as that of CO_2. If present trends continue, the combined concentrations of atmospheric CO_2 and other greenhouse gases would be radiatively equivalent to a doubling of CO_2 from pre-industrial levels possibly as early as the 2030's.

- The most advanced experiments with general circulation models of the climatic system show increases of the global mean equilibrium surface temperature for a doubling of the atmospheric CO_2 concentration, or equivalent, of between 1.5 and 4.5°C. Because of the complexity of the climatic system and the imperfections of the models, particularly with respect to ocean-atmosphere interactions and clouds, values outside this range cannot be excluded. The realization of such changes will be slowed by the inertia of the oceans; the delay in reaching the mean equilibrium temperatures corresponding to doubled greenhouse gas concentrations is expected to be a matter of decades.

- While other factors such as aerosol concentrations, changes in solar energy input, and changes in vegetation may also influence climate, the greenhouse gases are likely to be the most important cause of climate change over the next century.

- Regional scale changes in climate have not yet been modelled with confidence. However, regional differences from the global averages show that warming may be greater in high latitudes during late autumn and winter than in the tropics; annual mean runoff may increase in high latitudes; and summer dryness may become more frequent over the continents at middle latitude in the Northern Hemisphere. In tropical regions, temperature increases are expected to be smaller than the average global rise, but the effects on ecosystems and humans could have far reaching consequences. Potential evapotranspiration probably will increase throughout the tropics whereas in moist tropical regions convective rainfall could increase.

- It is estimated on the basis of observed changes since the beginning of this century, that global warming of 1.5°C to 4.5°C would lead to a sea-level rise of 20-140 centimeters. A sea level rise in the upper portion of this range would have major direct effects on coastal areas and estuaries. A significant melting of the West Antarctic ice sheet leading to a much larger rise in sea level, although possible at some future date, is not expected during the next century.

- Based on analyses of observational data, the estimated increase in global mean temperature during the last one hundred years of between 0.3 and 0.7°C is consistent with the projected temperature increase attributable to the observed increase in CO_2 and other greenhouse gases, although it cannot be ascribed in a scientifically rigorous manner to these factors alone.

- Based on evidence of effects of past climatic changes, there is little doubt that a future change in climate of the order of magnitude obtained from climate models for a doubling of the atmospheric CO_2 concentration could have profound effects on global ecosystems, agriculture, water resources and sea ice.

RECOMMENDED ACTIONS

1. Governments and regional inter-governmental organizations should take into account the results of this assessment (Villach 1985) in their policies on social and economic development, environmental programmes, and control of emissions of radiatively active gases.

2. Public information efforts should be increased by international agencies and governments on the issues of greenhouse gases, climate change and sea level, including wide distribution of the documents of this Conference (Villach 1985).

3. Major uncertainties remain in predictions of changes in global and regional precipitation and temperature patterns. Ecosystem responses are also imperfectly known. Nevertheless, the understanding of the greenhouse question is sufficiently developed that scientists and policy-makers should begin an active collaboration to explore the effectiveness of alternative policies ad adjustments. Efforts should be made to design methods necessary for such collaboration.

   (i) Governments and funding agencies should increase research support and focus efforts on crucial unsolved problems related to greenhouse gases and climate change. Priority should be given to national and international scientific programme initiatives such as (a) the World Climate Research Programme (WMO-ICSU), (b) present and proposed efforts on biogeochemical cycling and tropospheric chemistry in the framework of the Global Change Programme proposed by ICSU, (c) National Climatic Research Programmes. Special emphasis should be placed on improved modelling of the ocean, cloud-radiation interactions, and land surface processes.

   (ii) Support for the analysis of policy and economic options should be increased by governments and funding agencies. In these assessments the widest possible range of social responses aimed at preventing or adapting to climate change should be identified, analyzed and evaluated. These assessments should be initiated immediately and should employ a variety of available methods. Some of these analyses should be undertaken in a regional context to link available knowledge with economic decision-making and to characterize regional vulnerability and adaptability to climatic change. Candidate regions may include the Amazon Basin, the Indian subcontinent, Europe, the Arctic, the Zambezi Basin, and the North American Great Lakes.

4. Governments and funding institutions should strongly support the following:

(i) Long-term monitoring and interpretation with state-of-the-art models of:

(a) radiatively important atmospheric constituents in addition to CO_2, including aerosols;

(b) solar irradiance; and

(c) sea level.

(ii) Study and interpretation of the past history of climate and environment, specially regarding interactions among the atmosphere, oceans and ecosystems.

(iii) Studies of the effects of atmospheric composition and of changing climate and climatic extremes on sub-tropical and tropical ecosystems, boreal forests, and on water regimes.

(iv) Investigations of the sensitivity of the global agricultural resource base with respect to:

(a) direct effects of increases in atmospheric CO_2 and other greenhouse gases;

(b) effects of changes in climate; and

(c) probable combinations of these.

(v) Evaluation of social and economic impacts of sea level rises.

(vi) Analysis of policy-making procedures under the kinds of risks implied by a significant greenhouse warming.

5. UNEP, WMO and ICSU should establish a small task force on greenhouse gases, or take other measures, to:

(i) help ensure that appropriate agencies and bodies follow up the recommendations of Villach 1985;

(ii) ensure periodic assessments are undertaken of the state of scientific understanding and its practical implications;

(iii) provide advice on further mechanisms and actions required at the national or international levels;

(iv) encourage research in developing countries to improve energy efficiency and conservation;

(v) initiate, if deemed necessary, consideration of a global convention.

THE NEW YORK TIMES, SUNDAY, NOVEMBER 3, 1985

Scientists Warn of Earlier Rise in Sea Levels

By PHILIP SHABECOFF

Special to The New York Times

WASHINGTON, Nov. 2 — Scientists from 29 nations say governments must develop economic and social plans on the assumption that the world's climate will be warmer and its sea levels higher early in the next century.

At a meeting last month in Villach, Austria, the scientists agreed that accumulated carbon dioxide and other gases in the atmosphere could cause temperatures to rise to higher levels than any on record.

The scientists also agreed that growing evidence indicated the warming trend and the subsequent melting of polar ice and a rise in sea levels were likely to come in the first half of the 21st century rather than later, as had been projected.

The trend is a result of rising levels of carbon dioxide, created largely from the burning of such fossil fuels as coal, and other gases that allow radiation to enter the atmosphere from the sun but do not let it escape the atmosphere. The gases, in effect, act as a greenhouse, retaining the sun's heat.

Policies and Influence on Trend

In a concluding statement, the scientists said that while "some warming of climate now appears inevitable, the rate and degree of future warming could be profoundly affected by governmental policies on energy conservation, use of fossil fuels and the emission of some greenhouse gases."

The meeting was called by the United Nations Environment Program, the World Meteorological Organization and the International Council of Scientific Unions. The United States, the Soviet Union and China were represented.

The statement also said changes in climate and sea level caused by greenhouse gases were linked with such environmental issues as acid rain and threats to the earth's protective ozone layer from chloro-fluorocarbons from aerosol compounds, foams and other products.

Acid rain is created as sulfur and nitrogen oxides produced in burning coal and other industrial fossil fuels are carried aloft and return to earth as precipitation; the acidic deposits can harm to aquatic and plant life.

Dennis A. Tirpak of the Environmental Protection Agency's Office of Policy Analysis said at Villach that the scientists reached a quick consensus that governments should go beyond research and turn toward economic and social policies.

Many Gases Play a Role

It was originally thought that carbon dioxide was the main problem, but recently there has been widening agreement that such gases as methane from natural biological processes, the chloro-fluorocarbons and nitrous oxides created from using fertilizers contribute to the greenhouse effect.

The accumulation of the gases, the conferees said, is projected to warm the average surface temperature of the earth by 2.7 degrees to 8.1 degrees Fahrenheit in the first half of the next century, although uncertainties about the process may suggest changes beyond that range. Melting ice could raise the sea level by 10 inches to 4 feet or more, the statement said.

"Many important economic and social decisions," it said, "are being made today on major irrigation, hydropower and other water projects; on drought and agricultural land use; on structural designs and coastal engineering projects, and on energy planning, all based on assumptions about climate a number of decades into the future."

'A Matter of Urgency'

Because of the greenhouse effect, the conferees said, "It is a matter of urgency to refine estimates of future climate conditions."

They also said reducing use of coal and oil and conserving energy to reduce acid rain would reduce the concentrations of gases.

Dr. Irving M. Mintzer, director of the energy and climate program for the World Resources Institute, a private organization that conducts research and recommends policies, said the consensus "means that governments and policy analysts can't be complacent."

Stamps of Presidents Due

WASHINGTON, Nov. 2 (AP) — A series of miniature sheets of commemorative stamps featuring the White House and the 35 Presidents who have died will be issued by the Postal Service next year.

February 7, 1985

Honorable David Durenberger, Chairman
Subcommittee on Toxic Substances and
Environmental Oversight of the
Committee on Environment and Public Works
United States Senate
Washington, D.C. 29510

Dear Mr. Chairman:

We appreciate the opportunity to submit a statement for the printed record of hearings on the environmental effects of atmospheric warming.

The Environmental Dialogue Group, convened by the Edison Electric Institute, consists of twelve participants: six from the electric utility industry and six from national environmental organizations. Since its inception in early 1984, the Group has met on numerous occasions to discuss environmental issues significant to public and private interests. These informal and off-the-record meetings are designed to provide a dialogue between parties often in disagreement but willing to pursue solutions to environmental problems. The Group convened a two-day workshop on January 15, 1985 to discuss the scientific understanding and possible environmental impacts of the measured increases of atmospheric carbon dioxide and other trace gas concentrations.

The Workshop included presentations by and discussions with some of the most respected scientists and policy makers presently involved in private and governmental research concerning the many aspects of this complex meteorological phenomenon. Dr. Stephen Schneider of the National Center for Atmospheric Research presented a basic overview of the major technical issues associated with carbon dioxide and possible global warming. Dr. Frederick Koomanoff, Director of the U.S. Department of Energy's Carbon Dioxide Research Division, described the Agency's efforts to coordinate its ten-year research effort to quantify possible changes in sea level, precipitation and atmospheric warming. Dr. John Hoffman, Director of the Strategic Study Staff of the U.S. EPA, discussed the role of other "trace" gases in the atmosphere and their contribution to the global warming process. Dr. Marvin Miller, a visiting scholar at the U.S. Arms Control and Disarmament Agency, described the difficulties facing nations in their effort to secure international cooperation on the issue of global warming.

Finally, Dr. Irving M. Mintzer, Senior associate of the World Resources Institute pointed out how the ability to respond to trace gas-induced climate change among nations depends upon the education level of the population, its income and economic structure as well as upon the specifics of its geography.

As a result of our deliberations, the Group reached a deep appreciation of the complexity and wide ranging implications of global atmospheric warming and the options the world community must explore and decide upon, if a response is to be made in time for a positive result. It became apparent to us that accelerated research efforts backed by a stronger financial commitment by the world's governments must be the highest priority for those in a position to affect the course of this global atmospheric problem. It was with that spirit, the undersigned drafted the following Statement of Concerns regarding the Greenhouse effect.

Statement of Concerns

We are concerned that there is not enough knowledge available to understand fully the issues which arise from the accumulation of CO_2 and other trace gases in the atmosphere -- the so-called "greenhouse effect." The questions involved are highly complex, of an international character, and deal with scientific, social, technical, and economic matters. In addition to those already in effect, new programs must be undertaken to address these important issues.

Our most important concern is the need for additional research in these major areas:

- Adequacy of predictive models. The general circulation models must become more sophisticated in their treatment of linkages between oceans and the atmosphere and between clouds and atmosphere.
- Adequacy of physical data. Data on atmospheric concentrations of carbon dioxide and other gases, global temperature measurements, and a host of other phenomena are important to model estimation and verification.
- The distribution of changes in climate and weather patterns that might result from global warming.
- Possible physical effects of climate change. Among the most important of these effects are those on fisheries, agriculture, and other plant and animal species as well as upon glacial ice and, consequently, sea level.

- Socioeconomic impacts resulting from changed climate or efforts to avoid it. These include the costs associated with potentially altered agricultural production, increased sea level, etc., as well as the costs (and efficacy) of attempts to avoid such warming. Research is also needed on possible technologies to control greenhouse gases and on the extent to which any warming that may take place is irreversible.
- Adaptive strategies. More knowledge is needed about ways in which infrastructural development might be shifted or modified to reduce its sensitivity to possible climate changes. Also required, is research into other means of adaptation including genetic engineering of plant species resiliant to altered climate.
- Public understanding and scientific cooperation. Sound policymaking requires the inputs of scientists from a wide variety of disciplines and from a number of different countries. Both interdisciplinary and international cooperation should be facilitated. Similarly, an informed public is essential to policy development.

Related to this need for additional research, but important enough to bear separate mention, is the potential role of trace gases in greenhouse warming. To date, the question of greenhouse warming has been framed almost exclusively as a carbon dioxide problem; CO_2 is clearly a potentially quite important part of the problem. However, it appears that a collection of trace gases may exert an effect on climate equal to that associated with CO_2. This possibility must be the subject of additional research.

Finally, we are concerned that the international nature of possible global warming should be given more emphasis. This has important implications and it also points out the importance of international political institutions and organizations. These organizations could play an important role in providing information about the problem of greenhouse warming, and would surely have to play some role in any solution should one be necessary. Of importance in this international dimension is the adoption or development of energy efficient technologies. This issue is complicated by the need to accommodate increased per capita energy use in developing countries.

In conclusion, Mr. Chairman, we applaud your efforts to focus more public attention on this important matter and stand ready to do all that we can to assist you in continuing efforts to promote an international response through research, education and the development of energy efficient technologies.

Sincerely,

Jan Bea
Jan Beyea
National Audubon Society

John L McCormick
John L. McCormick
Environmental Policy Institute

W.J. Finnegan
W.J. Finnegan
Puget Sound Power & Light Co.

Gene L. Robinson
Gene L. Robinson
Illinois Power Co.

Michael M. Hertel
Michael Hertel
Southern California Edison Co.

W. Samuel Tucker Jr.
W. Samuel Tucker, Jr.
Florida Power & Light Co.

R.M. Lee
R.M. Lee
Boston Edison Company

H.J. Young
Edison Electric Institute

Ellen Winchester
Ellen Winchester
Sierra Club

Organizations and corporations are listed for affiliation purposes only.

ALLIANCE FOR RESPONSIBLE CFC POLICY
1901 N. FT. MYER DRIVE, SUITE 1204
ROSSLYN, VIRGINIA 22209
(703) 841-9363

February 25, 1986

Honorable David Durenberger
Chairman
Senate Subcommittee on Toxic Substances
and Environmental Oversight
410 Dirksen Senate Office Building
Washington, D.C. 20510

Dear Senator Durenberger:

I am submitting for your information and for the Committee's Hearing record, the comments of the Alliance for Responsible CFC Policy on the issue of global climate warming. This issue was the subject of hearings before your Committee on December 10, 1985.

The Alliance is a coalition of more that 500 companies, large and small, that use or produce chlorofluorocarbon chemicals (CFCs). CFCs are utilized in numerous essential products and uses including air conditioning and refrigeration systems; rigid and flexible foams used for insulation, packaging and furniture components; and to sterilize medical supplies and instruments. The annual value of goods and services which depend to a varying extent upon CFCs exceeds $28 billion, and more than 780,000 full-time jobs are related to CFC uses in the United States.

The Alliance has been working since 1980 to ensure that government directives and policies pertaining to CFCs are scientifically sound, balanced, and socially and economically effective.

Please do not hesitate to contact us if we can provide information in addition to these comments.

Sincerely,

Kevin J. Fay
Administrative Director

Enclosure

KJF:amp

HEARINGS ON
GLOBAL CLIMATE CHANGE

December 10, 1985

SENATE COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS
SUBCOMMITTEE ON TOXIC SUBSTANCES AND ENVIRONMENTAL OVERSIGHT

Comments by
The Alliance for Responsible CFC Policy

The Alliance for Responsible CFC Policy is pleased to present testimony for the record of the December 10, 1985 hearings on Global Climate Change before the Committee on Environment and Public Works, Subcommittee on Toxic Substances and Environmental Oversight. In addition to our prepared comments, transmitted herewith, we also offer brief comments on the testimony of Drs. Cicerone and Manabe.

The Alliance emphasizes that CFCs are projected to contribute to the theorized, calculated temperature increase at the earth's surface (the greenhouse effect) in any significant amount only if large increases in future CFC emissions occur.

Dr. Cicerone stated (page 5 of his testimony):

> "Generally speaking, we expect continued future growth rates of 2-5 percent per year or more in the emissions of these chemicals (i.e., CFCs) into the 21st century."

We emphasize further that CFCs are man-made chemicals. Major increases in CFC emissions cannot occur in the future without new commitments of large amounts of capital to build new production facilities.

As an example, a 5 percent annual increase in CFC emissions compounded annually would mean global emissions of CFCs in 2050 at 24 times the level of today's emissions. This implies that the current global manufacturing or production facilities for CFCs would also have to increase correspondingly at an estimated cost of several billion dollars annually, an unprecedented development in the history of the industry.

The Alliance is unaware of any expansion or new building program to increase the global production of CFCs at a rate even remotely approaching that required by the preceding discussion nor do we anticipate that such building programs will be initiated in the foreseeable future.

Dr. Cicerone (page 8) stated:

> "Also, global ozone changes are probably underway in the stratosphere because of man-made chlorofluorocarbon gases and the same methane and nitrous oxide increases I mentioned earlier. We think that ozone is decreasing in the upper stratosphere and increasing in the lower stratosphere with a net warming greenhouse effect." (emphasis added)

The Alliance notes that Dr. Cicerone's testimony is clearly speculative, reflecting the high degree of uncertainty associated with the ozone changes that he mentioned. Furthermore, even if measurable changes in stratospheric ozone should be confirmed, it would not be possible to distinguish among any of several possible causes, given the current state of scientific knowledge.

As an example, small measurable changes in ozone could be consistent with both man-made causes and natural variation. Although at some point in the future it should be possible to distinguish between these possibilities, it cannot be done now.

Finally, we wish to re-emphasize the important cautions stated by Dr. Manabe (page 6) in his testimony. The uncertainties in estimated future climate change are enormous, and continued research efforts will be needed to determine the magnitude of a future, average global temperature increase, if indeed one occurs, and to understand its downstream effects on climate.

Whatever the greenhouse effect, assuming for this discussion that it will occur, it is sure to be slow in coming. In our view, we should continue and strengthen existing research programs to better define the magnitude and nature of a possible greenhouse effect and, if necesary, to explore strategies to deal with it.

WILL CHLOROFLUOROCARBONS AFFECT CLIMATE?

A PAPER BY

THE ALLIANCE FOR RESPONSIBLE CFC POLICY

MAY, 1982

REVISED JANUARY, 1986

WILL CHLOROFLUOROCARBONS AFFECT CLIMATE?

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WILL CHLOROFLUOROCARBONS AFFECT CLIMATE?

I. INTRODUCTION

It has been claimed that a number of man's activities, including the emission of chlorofluorocarbons (CFCs), could lead to modification of the earth's climate. Many of these claims have taken scientific theories and data out of context, or have ignored scientific uncertainties and necessary qualifications. This has resulted in confusion and misconceptions.

This paper has been prepared to bring perspective to the discussion about climate. The paper explores which of man's activities may have an effect on climate, the potential contribution of CFCs, the uncertainties involved in estimating the potential impact of man's activities on climate, and the research needed to improve understanding of this complex scientific question.

II. THE IMPLICATIONS OF A CHANGE IN CLIMATE

Climate is the average of weather conditions over a number of years. It includes consideration of a number of features -- for example, temperature, rainfall, humidity and wind. All of the components of climate are interrelated, and if one feature were sufficiently altered, it could lead to change in the other features as well.

One key feature of climate is the average global temperature. This average has varied by about 2°F over the last century. While this variation is small compared to the kind of short term fluctuations we see in our seasonal weather patterns, there are indications that a change of a relatively few degrees in average global temperature could affect other elements of climate such as precipitation patterns, the extent of polar ice cover, prevailing winds and ocean currents. It is potential changes such as these that concern some scientists today.

III. HOW MAN'S ACTIVITIES MIGHT AFFECT CLIMATE

There are two avenues through which man's activities have been theorized to affect the earth's climate. The principal and better known avenue is the so-called "greenhouse effect," so named because of the higher temperatures associated with greenhouses resulting from solar heating. The less well known of these effects is called the "ozone redistribution effect" and is the outgrowth of concern in recent years that certain of man's activities may affect the ozone layer in the stratosphere.

A. The "Greenhouse Effect"

1. What Is It? - Most of the sun's energy reaches the earth as visible light. After passing through the atmosphere, this light energy is absorbed by the earth's surface and, in the process, is converted into heat energy. The earth -- now warmed by the sun -- radiates heat energy back into the atmosphere toward outer space.

The greenhouse effect occurs because naturally occuring gases, such as carbon dioxide and water vapor, absorb and thus retain some of this outgoing heat radiation. This process slows the heat loss, making the earth's surface warmer than it would be if this radiant heat had passed unobstructed through the atmosphere into space. The warmer earth's surface, in turn, radiates more heat until a dynamic balance is established between the incoming and outgoing energy. This warming process caused by the atmosphere's absorption of the heat energy radiated from the earth is called the greenhouse effect.

The greenhouse effect is an important part of the earth's natural system. Although we do not have the means to measure directly just how large an increase in surface temperature the greenhouse effect produces, scientists using computer simulations (called "models") of the atmosphere have calculated that the earth's surface would be about 60°F cooler than it is now if there were no greenhouse effect. To put this into perspective -- a drop in surface temperature of about 15°F to 20°F would create another ice age; and an earth that was 60°F cooler probably would be almost completely covered by ice. If the calculations are correct, the greenhouse effect plays a vital role in our natural environment.

There is growing concern, however, that man's activities might eventually increase this effect, thereby causing an additional temperature increase at the earth's surface. For example, the increase in the atmosphere of several gases due to man's activities is thought to have the potential of producing an "enhanced greenhouse effect." Principal among these is carbon dioxide. Others are trace gases, including CFCs, methane, ozone and nitrous oxide.

2. Carbon dioxide - Scientists know from measurements that the concentration of carbon dioxide (CO_2) is increasing in the atmosphere. This increase is due primarily to our use of fossil fuels. Projections of fossil fuel consumption suggest that the trend will continue for many decades.

Using computer models, scientists have attempted to calculate the impact of projected increases in CO_2 on the greenhouse effect. In 1983, the National Academy of Sciences reported that atmospheric CO_2 concentration will likely double by the last half of the next century. Computer simulation results indicate that this doubling of CO_2 concentrations could lead to an increase in the earth's average surface temperature of 3°F to 8°F.

At this time, however, scientists have not reached agreement on the net significance of such an increase in surface temperature, were it to occur. On one hand, some researchers have estimated the world would have a net gain, economically, from average surface temperature increases of up to about 2°F. But, on the other hand, the prehistoric record suggests that an increase in excess of 5°F to 9°F could lead to significant changes in sea level due to partial melting of the polar ice caps. The estimated range reported in 1983 by the National Academy of Sciences falls between these extremes.

3. CFCs and Other Trace Gases - CFCs, methane, and nitrous oxide are increasing in the lower atmosphere as a result of man's activities, and these gases also are calculated to enhance the greenhouse effect. However, the calculated long-term surface temperature change from each of these trace gases is smaller than that calculated for CO_2. For example, models calculate that the current portion of the enhanced greenhouse effect due to CFCs increases is only about one fourth (1/4) of that due to increases in atmospheric CO_2 concentrations. Future relative effects are dependent on changes in the emission rates of the gases and, hence, cannot be reliably estimated. However, the calculated contribution of CFC-11 and CFC-12 to the greenhouse effect in 2050 is 12% - 25% of that for CO_2, assuming CFC emissions in 2050 that range from no increase up to a factor of almost five times today's emissions, and doubled CO_2 concentrations by 2050.

B. The "Ozone Redistribution Effect"

1. What Is It? - For over a decade, concern has been expressed that certain emissions from man's activities may cause a reduction in the total amount of stratospheric ozone, resulting in an increase in ultraviolet light reaching the earth's surface. However, recent calculations of the theoretical effect of these emissions suggest that there may be little or no change in the net

total ozone for at least the next few decades. These same calculations suggest, however, that there may be some change in the vertical distribution of ozone as a result of changes in emissions of a number of gases including CFCs, methane, nitrous oxide, and CO_2. The calculated change is a loss of ozone in the upper stratosphere and a compensating gain of ozone in the lower stratosphere. This is termed the "ozone redistribution effect."

It has been suggested that such redistribution of ozone could affect the temperature patterns of the stratosphere, which in turn, might have an impact on climate. It is thought, however, that any impact of ozone redistribution on the climate would be negligibly small compared to that of an enhanced CO_2 greenhouse effect.

2. Discussion - The potential future effect of CFCs on stratospheric ozone is calculated using computer simulations of the atmosphere. Important improvements in these computer models have resulted in substantial decreases in the future potential ozone depletion calculated for CFCs when considered alone. But more importantly, the most advanced computer models now are able to calculate the theoretical combined effect of all of man's emissions thought to affect stratospheric ozone. This includes CFCs, certain chlorocarbons, nitrogen oxides from aircraft and agricultural operations, methane, and carbon dioxide. Considering the combined effects of all of these trace gas emissions simultaneously in the models is thought to be a more realistic simulation of the real atmosphere than considering the potential effects of CFCs alone.

These "multiple perturbation calculations," as they are called, suggest there are important offsetting and interacting effects between the various emissions. In fact, recent calculations of the combined effects of a number of these emissions suggest that total overhead ozone will remain essentially unchanged from current levels for decades. Uncertainties in these emissions make calculations for times beyond the next few decades virtually meaningless. Such multiple perturbation calculations substantially reduce concern about a possible increase in ultraviolet (UV) light reaching the earth's surface, because UV penetration is controlled by the total amount of overhead ozone.

Nevertheless, the same combined calculations which show no change in total ozone suggest there may be a reduction in the amount of ozone at 20-30 miles in altitude and a compensating increase in ozone at 6-15 miles. Because the distribution of ozone influences temperature throughout the stratosphere, a change in ozone distribution like that suggested by present computer models would lead to a change in stratospheric temperature patterns. Still, it should be understood that scientists have only just begun to analyze how such changes in temperature of the stratosphere would affect climate, should they occur.

IV. HOW CERTAIN ARE WE OF THESE EFFECTS ON CLIMATE?

As noted earlier, both the temperature changes associated with an enhanced greenhouse effect, and the theoretical redistribution of ozone are calculated using complex computer models designed to simulate atmospheric interactions mathematically. Although these models are different, there are similarities -- one being the great uncertainties associated with both models. In fact, whether the current model calculations for either effect have any value as predictions about the future is one of the important questions that still need answering.

Below, we examine in more detail some sources of uncertainty in the models, taking, as an example, the model used to calculate future potential temperature changes due to an enhanced greenhouse effect.

A. Sources of Uncertainty in the Models

The uncertainties associated with the models result from the many assumptions and simplifications that must be made in the attempt to simulate the real atmosphere. Some of these compromises are necessary because it would simply take the computer much too long to consider all of the variables involved. Others are necessary because scientists don't have sufficient information to be more precise.

For example, scientists know that the oceans have a potentially large moderating effect on any change in surface temperature. They know also that interactions between various climatic effects are important. It should be apparent, then, that simulating these influences accurately in the models is essential if meaningful calculations are to be performed. When attempting to develop a model of the atmosphere and climate, however, there is an important distinction between knowing that something has an effect and knowing how large or small that effect may be. It is the difficulty of determining just how large or small an effect these various factors have on the end result -- climate change -- that causes the large uncertainties associated with present model calculations.

The complexity of the problem facing the computer modelers can also be illustrated by considering some of the interactions between different elements of climate. Some of these interactions enhance temperature changes. For instance, warmer surface temperatures could increase the amount of water vapor in the lower atmosphere, which would enhance the greenhouse effect. Also, if there were a sufficiently warmer surface temperature there would be less ice and snow cover. Insofar as ice and snow reflect sunlight rather than absorb it, any reduction in ice and snow cover would mean that surface temperature would be increased.

Other interactions could have an opposite effect. Perhaps the most important, but least understood interaction, is with cloud cover. The size and direction of the cloud cover effect would be determined by changes in the altitude, temperature, thickness, distribution and global coverage of clouds. However, increased cloud cover resulting from warmer surface temperatures could reflect incoming sunlight and thereby lessen any increase in surface temperature, and an increase in particulate matter, e.g., from volcanoes and various activities of man, could also have a cooling effect on surface temperature, since high dust clouds reduce the amount of sunlight reaching the earth. The modeler's job is difficult and a good deal of approximation is necessary to come up with a functional (though not necessarily complete or accurate) model.

B. How Can We Check the Calculations?

Complete or not, current models of the atmosphere produce calculations -- and these models "calculate" that the rate of increase in surface temperature caused by the enhanced greenhouse effect resulting from man's overall activities may be about 0.2°F per decade -- a calculatd change that is presently too small to be detected. Estimates vary of the smallest change in surface temperature that could be detected by analysis of climatic data primarily because natural fluctuations obscure any long-term trend.

What this means, of course, is that the greenhouse effect, as calculated by current models, cannot be verified quantitatively at this time by looking at the climatic record. What may be possible within the next decade or two, though, is for scientists to use the climatic record to define the upper limit of any greenhouse effect that may actually be occurring.

Moreover, scientists are evaluating other less direct methods for detecting surface temperature changes. One such method involves the use of satellite measurements. None of these methods is yet sufficiently developed to the extent that it can be used to determine unambiguously whether the surface temperature increases being calculated by the computer models are actually taking place.

In the case of the potential ozone redistribution effect, computer calculations of the possible impact of this effect on climate are very speculative. This is because the uncertainties are so great as to render any calculation essentially meaningless. Increased use of satellite measurements should answer the questions of whether the continued emission of CFCs will lead to an ozone redistribution. But even if we knew that ozone were being partially redistributed, techniques are not yet sufficiently developed to determine the climatic consequences, if any, of any such change in stratospheric ozone.

V. CONCLUSIONS

Calculations that an increase in the so-called greenhouse effect will bring about a slow rise in the earth's surface temperature have generated concerns about possible future changes in climate resulting from man's activities. Although carbon dioxide emissions are the primary concern, emissions of other gases -- including, but not limited to CFCs -- may also enhance the greenhouse effect. In the case of CFCs alone, however, the current effect is calculated to be only about one fourth (1/4) that of CO_2. This effect has not been measured; it is calculated by atmospheric models.

In addition, man's release of CFCs and some other gases to the atmosphere may lead to a change in the altitude distribution of stratospheric ozone, which might also lead to a surface temperature change. Any surface temperature effect from changes in ozone distribution is highly speculative, and if it occurred would be small relative to the greenhouse effect from carbon dioxide emissions.

When considering possible changes in surface temperature, it is important to understand that such changes are calculated using complex but imperfect computer models of the atmosphere. Verifying these calculations against actual meteorological records probably will not be possible for a decade or more, but any changes, if they occur, will take place slowly. In the interim, substantial further research can and should be performed.

Key research needs include improvements in modeling, increased monitoring of the climate, and more sensitive analysis of the climatic record to increase our ability to detect even small surface temperature changes due to man-made emissions -- should such changes actually occur. Much work along these lines already is underway, and the pace is accelerating. As an example, the Chemical Manufacturers Association's Fluorocarbon Program Panel is now engaged in an effort to develop an atmospheric model that couples the radiative dynamic and chemical effects of trace gases in the stratosphere and troposphere. This should permit more realistic studies of these effects on the temperature structure of the atmosphere and their contribution to the greenhouse effect.

In summary, the issue of potential climate modification is exceedingly complex, the uncertainties in our knowledge are great, and validation of the computer calculation is, at present, almost nonexistent. It currently seems that CFCs would not have a major relative impact on climate even if the various theories prove to be correct. However, the area of climate change -- from natural causes and that possibly induced by human activities -- is one requiring considerably more study.

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